SEWAGE AND INDUSTRIAL WASTES

(Formerly Sewage Works Journal)

JOURNAL of the FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

Special Features

Protective Coatings—Heukelekian and Crosby

Effects of Radioactivity on B.O.D.—Grune

Chromium Wastes—A Symposium

Milk Waste Treatment—Horton and Trebler

AUGUST, 1953—VOL. 25, No. 8

Make Plans to Attend

TWENTY-SIXTH ANNUAL MEETING

OF THE

FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

IN CONJUNCTION WITH

FLORIDA SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

BAYFRONT AUDITORIUM

MIAMI, FLORIDA

October 13-16, 1953

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HOTELS	Single (per room)	Double (per room)	Suites
Alcazar	$4–$5	$5–$8	$12–$14
Biscayne Terrace	.....	$8–$12	$20–$24
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FSIWA Housing Committee
320 N. E. Fifth Street
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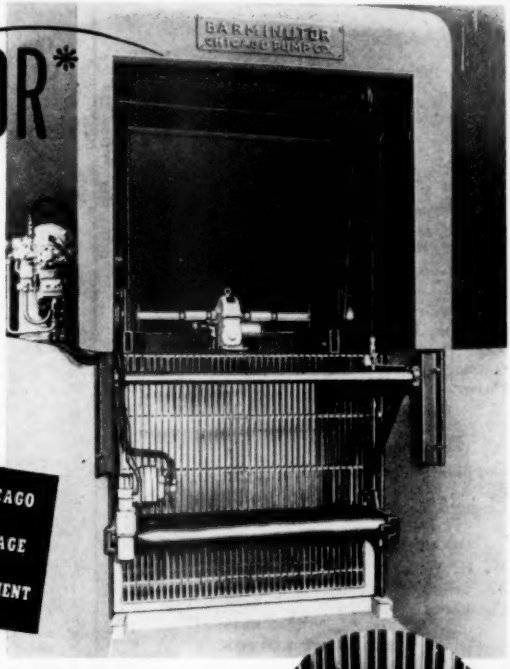
indicating at least first, second, and third hotel choices. Confirmation of the reservation will be received directly from the hotel accepting the reservation.

BARMINUTOR*

A New Comminution Development

CHICAGO SEWAGE EQUIPMENT



Barminutor installed in 5' channel.

The Barminutor Model "A" exclusively provides the advantages of comminution with maximum economy for flows from 10 to 15 M.G.D. Screening and cutting of coarse sewage material is accomplished without removal from the flow, maintaining continuous cleaning of the screen. The Barminutor, developed and tested over five years, based on fifteen years successful experience with the Comminutor, eliminates odors and handling nuisance in the screening process. High rate cutting in the flow — comminution — provides low maintenance cost and long life for cutting parts.

In tests conducted on a Barminutor installed at the Indianapolis, Indiana Sewage Treatment Plant, the unit was subjected to test loads of screenings up to six times normal load for 40 M.G.D. This material was comminuted and the screen completely cleaned in six minutes. Even with this heavy load head loss through the screen did not exceed 6". Like the Comminutor, power requirements are low.

FUNCTION OF THE BARMINUTOR

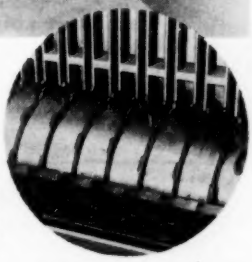
1. Cleaning the ¾" vertical bar screen and cutting of the screenings is accomplished by continual travel of the comminuting unit at 8 ft. per minute. Both upward and downward travel is controlled by an electric reversing brake motor.

2. The cutters on the comminuting unit, rotating at 400 R.P.M., travel within slots of the U-shaped bars and carry coarse material to the combs for cutting.

3. The direction of rotation automatically reverses when the direction of travel changes. The combs automatically position themselves to accomplish rapid cutting for each direction of rotation.

4. Uncuttable material is automatically rejected without damage to the cutting parts.

5. Rotation of cutters, position of combs and rejection of uncuttable material is accomplished through oil powered hydraulic system.



Close-up of Cutters and Combs. Cutters rotate within slots of Bar and Comb.

*Chicago Pump Company's trade name for its new screening and comminuting device for large sewage flows from 10 M.G.D.

CHICAGO PUMP COMPANY

SEWAGE EQUIPMENT DIVISION

622 DIVERSEY PARKWAY — **CHICAGO 14, ILLINOIS**

Flush Kleen, Screw-Pellet, Plunger, Horizontal and Vertical Non-Clogs Water Seal Pumping Units, Samplers

Swing Diffusers, Stationary Diffusers, Mechanical Aerators, Combination Aerator-Clarifiers, Comminutors.

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SEWAGE AND INDUSTRIAL WASTES

REG. U. S. PAT. OFF.

A monthly Journal devoted to the advancement of fundamental and practical knowledge concerning the nature, collection, treatment and disposal of sewage and industrial wastes, and the design, construction, operation and management of such works.

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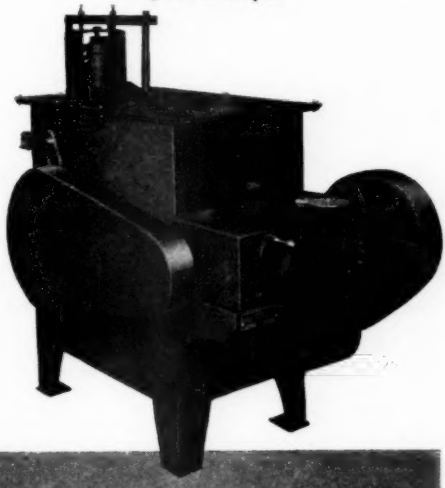

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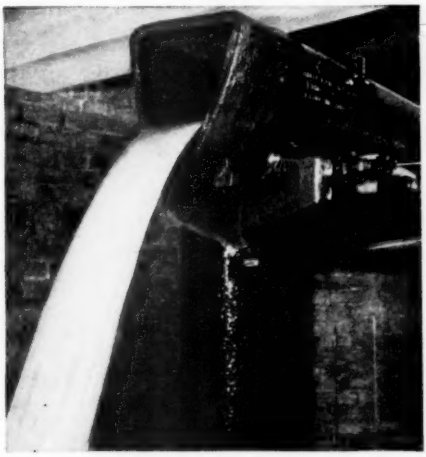
For Accurate Measurement of

RAW WATER, TRADE WASTES, SEWAGE



Specify **SIMPLEX TYPE S PARABOLIC FLUME**

Intelligent planning of industrial waste or sewage treatment facilities requires accurate flow data. Accurate control of processes and dosages are wholly dependent on accurate flow measurements.

Quite often, conventional types of primary devices can't answer this basic question because of adverse conditions such as: low flows under low head conditions; very wide flow ranges; heavy sediment or suspended solids; size, layout or grade of existing approach section; corrosive liquors in channels or pipes.

Simplex Type S Parabolic Flume was designed specifically to master *all* of these problems . . . accurately measures free-flowing wastes or sewage over a FULL 20 to 1 flow range!

Compact Type S Parabolic Flume is simple to install . . . requires a minimum of supporting structure, as shown in the above installation. Carefully machined levelling pins assure the correct grade for accuracy. No special approach section is needed.

Available in standard pipe sizes of 6″ to 36″, with bell, spigot or flanged inlet, Type S Parabolic Flume can be attached to even larger pipe sizes by means of eccentric reducers.

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MEMBER ASSOCIATION MEETINGS

Association	*Place*	*Time*
Pennsylvania Sewage and Industrial Wastes Assn.	Pa. State College, State College, Pa.	Aug. 26–28, 1953
West Virginia Sewage and Industrial Wastes Association	Hotel Morgan, Morgantown, W. Va.	Sept. 2–3, 1953
Iowa Sewage Works Assn.	Iowa State College, Ames, Iowa	Sept. 2–4, 1953
Rocky Mountain Sewage Works Association	Hotel La Fonda, Santa Fe, N. M.	Sept. 21, 1953
Kentucky-Tennessee Industrial Wastes and Sewage Works Assn.	Owensboro Hotel, Owensboro, Ky.	Sept. 21–23, 1953
Michigan Sewage and Industrial Wastes Association	Michigan State College, Kellogg Center, East Lansing, Mich.	Sept. 21–23, 1953
South Dakota Water and Sewage Works Conference	Alex-Johnson Hotel, Rapid City, S. Dak.	Sept. 22–24, 1953
Georgia Water and Sewage Association	Georgia Institute of Technology, Atlanta, Ga.	Sept. 23–25, 1953
Missouri Water and Sewerage Conference	Elms Hotel, Excelsior Springs, Mo.	Sept. 27–29, 1953
North Dakota Water and Sewage Works Conference	Leland Parker Hotel, Minot, N. Dak.	Oct. 1–2, 1953

TWENTY-SIXTH ANNUAL MEETING

Federation of Sewage and Industrial Wastes Associations
in conjunction with
Florida Sewage and Industrial Wastes Association
Municipal (Bayfront Park) Auditorium, Miami, Florida
October 13–16, 1953

Address hotel reservation requests to: FSIWA Convention Housing Bureau, 320 N.E. Fifth Street, Miami, Florida

Canadian Institute on Sewage and Sanitation	General Brock Hotel, Niagara Falls, Ont., Can.	Oct. 26–28, 1953
New England Sewage and Industrial Wastes Association	Wannamoisett Country Club, 96 Hoyt Avenue, East Providence, R. I.	Nov. 5, 1953
Pacific Northwest Sewage and Industrial Wastes Association	Hotel Chinook, Yakima, Washington,	Nov. 5–7, 1953
North Carolina Sewage and Industrial Waste Association	Sheraton Hotel, High Point, N. C.	Nov. 9–11, 1953
Nebraska Sewage and Industrial Wastes Association	Hotel Capital, Lincoln, Nebr.	Nov. 12–13, 1953
Oklahoma Water, Sewage and Industrial Wastes Conference	Okla. A & M College, Stillwater, Okla.	Nov. 16–20, 1953

Briefs from the YEOMANS GUARD

Overall Removal of 91.7 Per Cent at Hope, Ark. Treatment Plant . . . Full Report Available

Have you on file the Hurwitz report?—a complete performance report on the Sewage Treatment Plant at Hope, Arkansas, by E. Hurwitz, Chief Chemist of the Sanitary District, Chicago.

The Hope plant is a single-stage Aero-Filter plant in which both primary and final settling is accomplished by Apiraflo clarifiers. It is designed for a population of 5,000 and an ultimate 10,000.

Average removal of suspended solids by primary clarifier was 70 per cent and B.O.D. removal 47.7 per cent. Over-all removal effected by the plant was 91.7 per cent.

The Hurwitz Report, complete with tabulated data, is yours for the asking.

☐ Please send the Hurwitz Report

easy
- *to select*
- *to install*
- *to pay for*

this NEW PACKAGE SEWAGE LIFT STATION

A practical answer to an urgent and growing need for a low-priced, easily installed "package" dry pit sewage lift station for small residential units: our new "Package" Sewage Ejector Series 6280.

No Selection Problem—A simple matter to choose the right model by *population to be served* and the discharge head.

No Installation Problem—It's a "package"—complete, ready to place in the pit and connect.

No Payment Problem—simple in design, standardized, this compact unit is low priced, easy to pay for.

See Bulletin 6251, page 8.

☐ Please send Bulletin 6251.

Difficult Industrial Wastes Successfully Treated in Yeomans Plants

A number of industrial wastes, including some described as "difficult," are being treated in Yeomans plants—with results described in some instances as "miraculous."

Efficient treatment is the main objective, of course; but the extraordinarily low cost of Yeomans plants—as to both construction and operation—is a factor that is pleasant to consider.

If you have a knotty problem of industrial waste treatment, it makes much sense at absolutely no cost to find out how we may be able to help solve it. Just write a letter.

The Yeomans Guard, published several times a year, is a compendium of news and useful information covering the pumping of materials and the treatment of wastes, both domestic and industrial. We shall be pleased to send you the current issue if you'd care to have it. Ask your local Yeomans Representative—listed in the telephone book yellow pages under "Pumps"—or write direct.

YEOMANS BROTHERS COMPANY

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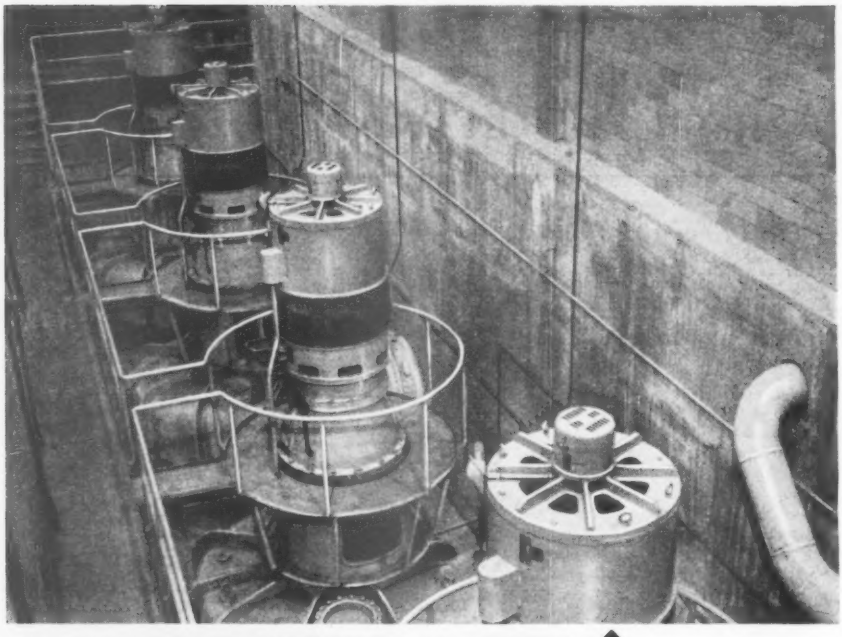
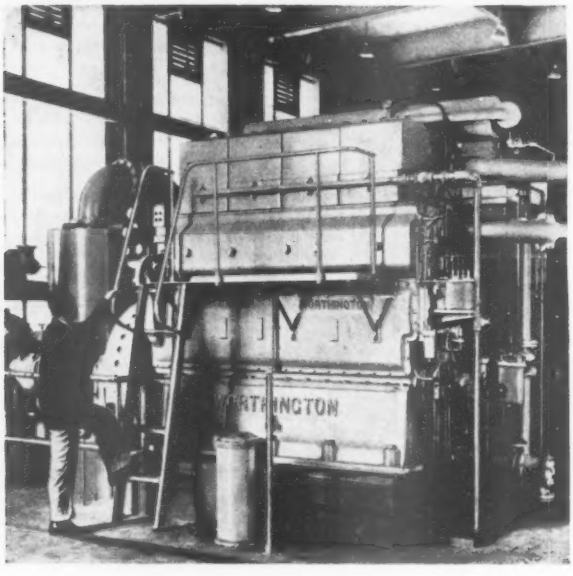
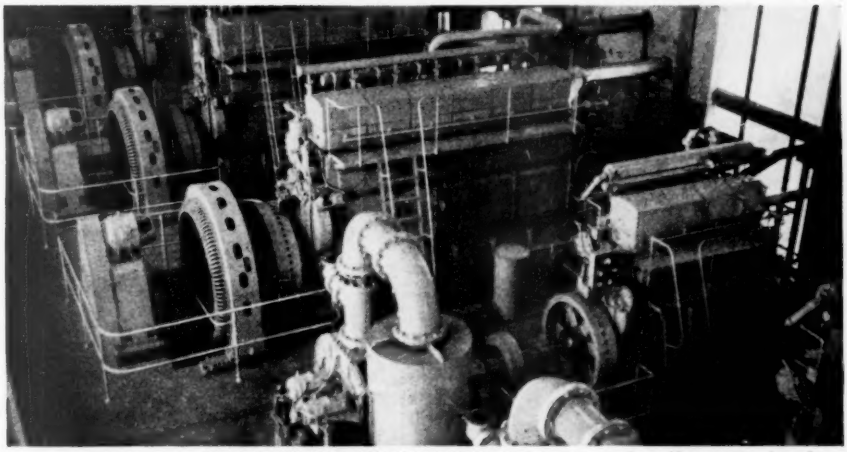
Manufacturers of: Centrifugal Pumps and Pneumatic Ejectors for Buildings, Municipalities, and Industrial Applications, and a Full Line of Waste Treatment Equipment.





FOUR OF THESE WORTHINGTON MIXFLO PUMPS, each with a capacity of 83 million gallons per day, move sewage through various stages of its treatment at Boston's Nut Island Plant. The pumps are designed to operate at variable speeds through the use of the magnetic drive which in connection with Worthington float control will maintain a pump-well level of not more than 3 inches above or below normal—even though pumping rates vary between 35 and 300 mgd.

PRESENTLY USING SEWAGE GAS AS FUEL, these Worthington dual fuel engines are designed to operate on either gas or oil. They will maintain load in the event of a sudden emergency loss of gas supply by automatically switching to oil. Two of these 215-hp units drive the sewage aeration blowers at Boston's new sewage treatment plant at Nut Island.



DUAL FUEL ENGINES AUTOMATICALLY MAINTAIN LOAD in the event of a sudden emergency loss of gas supply. These two 820-hp dual fuel engines and one 830-hp spark ignition gas engine drive three Electric Machinery generators. Two 215-hp dual fuel engines in the foreground drive positive displacement blowers.

Worthington equipment at Nut Island Plant helps Boston reclaim Quincy Bay beaches

Mixflo pumps have maximum capacity of more than 300 mgd of sewage

The new $10,000,000 Nut Island Plant at Quincy, Mass., is now treating 95 mgd of raw sewage which was previously pumped directly into Quincy Bay.

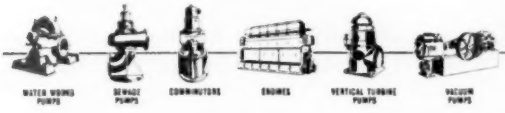
Four large Worthington Mixflo pumps, with Electric Machinery motor and magnetic drive, each with a capacity of 83 mgd, give this modern sewage treatment plant a reserve potential to meet any future demands.

Three large Worthington dual fuel engines drive the Electric Machinery generators which power the entire plant. Two smaller Worthington dual fuel engines drive the blowers for aeration of the sewage.

In addition to its larger pumps and engines shown here, Worthington also supplies comminutors, smaller sewage pumps, sludge removal pumps, and vertical turbine pumps for the water and sewage field.

Write us for a list of Worthington installations in your area, and complete information on how Worthington equipment can solve your sewerage problem. Worthington Corporation, Public Works Division, Section W.3.1, Harrison, N. J.

W.3.1



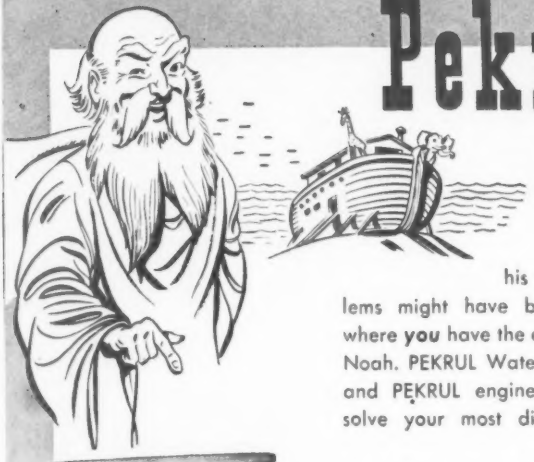
All Major Public Works Equipment Under One Responsibility

WORTHINGTON

Public Works Equipment

If Noah had known about...

Pekrul Gates



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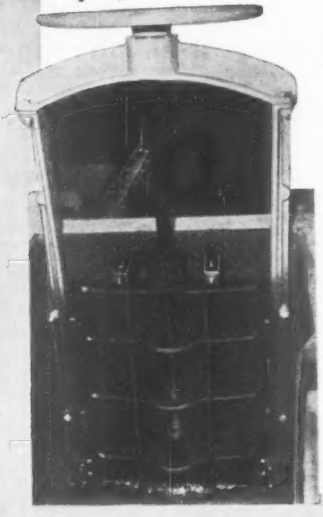

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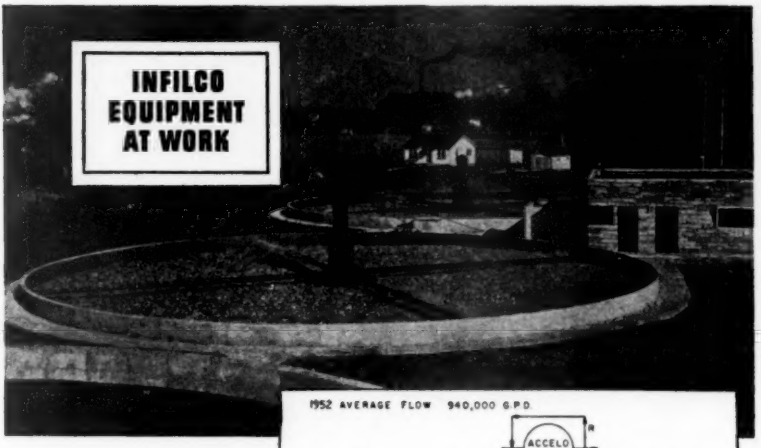

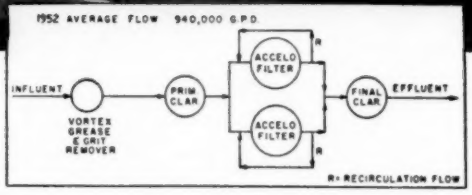

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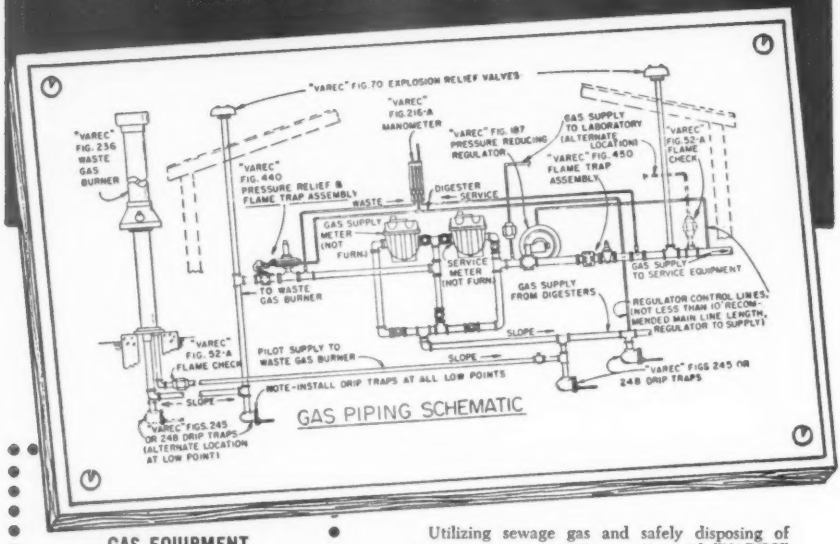
"VAREC" FIG. 70 EXPLOSION RELIEF VALVES
"VAREC" FIG. 236 WASTE GAS BURNER
"VAREC" FIG. 216-A MANOMETER
"VAREC" FIG. 187 PRESSURE REDUCING REGULATOR
GAS SUPPLY TO LABORATORY (ALTERNATE LOCATION)
"VAREC" FIG. 52-A FLAME CHECK
"VAREC" FIG. 440 PRESSURE RELIEF & FLAME TRAP ASSEMBLY
"VAREC" FIG. 450 FLAME TRAP ASSEMBLY
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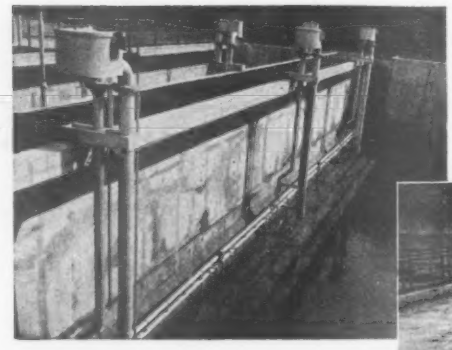
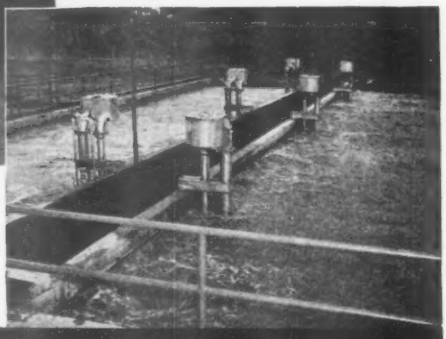


DIFFUSAIR installation at Kirkwood, Mo. Impingement nozzles and bowls are on headers at lower left side of tank.



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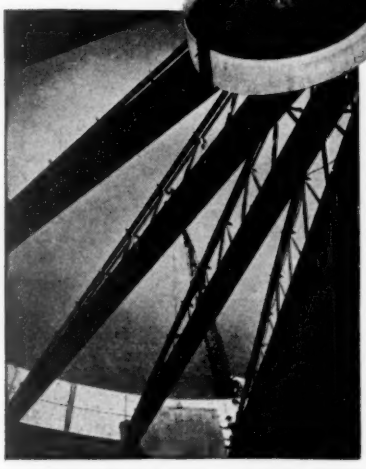

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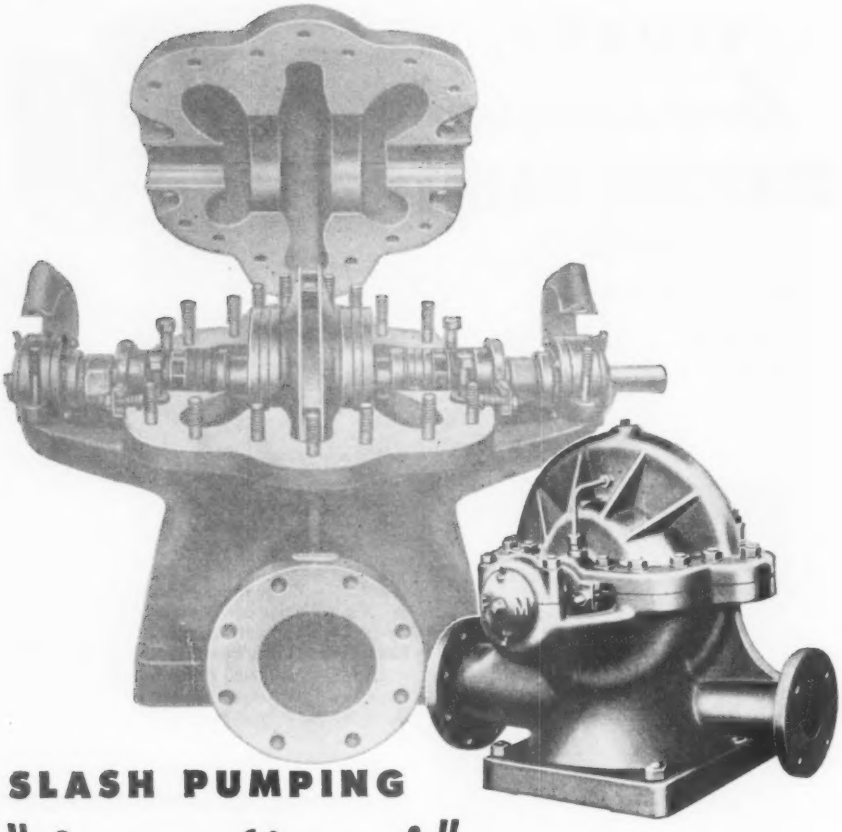

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SEWAGE AND INDUSTRIAL WASTES

Journal of the Federation of Sewage and Industrial Wastes Associations

Volume 25 | August, 1953 | Number 8

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Sewage Works

PROTECTIVE COATINGS AND SLIME GROWTHS *

By H. Heukelekian and E. S. Crosby

Department of Sanitation, Rutgers University, New Brunswick, N. J.

Slime growth on submerged surfaces in contact with waters polluted with sewage and industrial wastes is a common phenomenon and causes considerable maintenance and operating problems, as well as economic losses because of corrosion, deterioration, increased friction, etc. The fouling of surfaces resulting from the attachment and growth of organisms on such surfaces occurs in sewers at the water margin, where the growths at times attain great length. These growths float with the current, and frequently break off early in the spring, when they are carried to the treatment plant. The role played by the growths in the sewer is not clearly understood, although some investigators believe that they contribute to the septicity of the sewage and to hydrogen sulfide production.

They also occur, attached to the side walls below the liquid level, in sedimentation tanks holding sewage or industrial wastes. In gravity separators for petroleum refining wastes, the growths absorb the oils. When these masses become detached the oil may be released to the effluent. Slime coatings also occur in cooling-water circuits, in plant processing units, in papermaking machines, and in water lines.

All types of construction materials, such as wood, concrete, and iron, furnish anchorage and support to slime. Because concrete is so extensively used in contact with sewage and industrial wastes, both in sewers and in treatment units, and because its deterioration is a matter of current concern, its use as a basic surface for study appears logical.

The types of organisms that produce slime growths vary with the type and concentration of food materials and with environmental conditions. They include zoogleal and filamentous bacteria, fungi, algae, protozoa, and occasionally other invertebrates, such as worms and insect larvae. In waters containing various types of organic materials, slime growths are most abundant, but the nearly complete exclusion of organic material does not prevent their accumulation. Some of the organisms can grow on purely inorganic materials such as iron (iron bacteria), inorganic sulfur compounds (sulfur bacteria), ammonia (nitrifiers), and carbon dioxide (algae).

Of the environmental factors, pH, temperature, and the presence or absence of dissolved oxygen profoundly influence the nature and quantity of growth.

Various types of protective coatings have been developed for the purpose of controlling these growths, but little experimental evidence is available to determine their functions. As a part of some fundamental studies on the factors influencing the nature and quantity of growth, a study was made under field conditions on the effect of some commercially available paints and protective coatings on the amount of slime growth.

* Paper of the Journal Series, New Jersey Agricultural Experiment Station. Presented at Atlantic City, N. J., Meeting of the American Chemical Society, Sept. 1952.

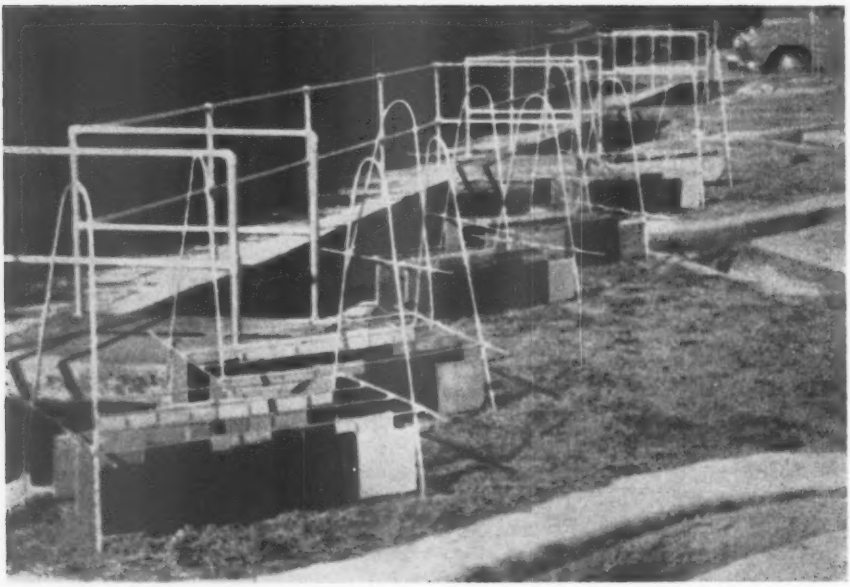

FIGURE 1.—Welded reinforcing rod racks were used to hold plates in open effluent channels of settling tanks.

Methods and Materials

Concrete test plates were prepared according to specifications recommended by the Portland Cement Association. The plates were 7½ by 7½ by ¾ in. in size and were of three types, as follows:

1. Standard Portland cement.
2. Standard Portland cement with copper oxide.
3. Antibacterial cement.

The copper oxide powder was added in concentrations of 1 and 5 per cent on the basis of the weight of Portland cement in the dry mix. The antibacterial cement was supplied by the manufacturer of this material and although the biological inhibitor in it was not disclosed, Knapp and Amberg (1) state that it contains 0.7 per cent pentachlorophenol.

The concrete plates were kept moist for one day, removed from the forms, and cured by submergence in water for three days. The surfaces of all plates were finished with a carborundum mason block, brushed, and washed.

The Portland cement plates were etched by being dipped into muriatic acid (10 per cent) and rinsed with water. After drying, a number of the plates were coated and others were set aside as controls. In all, 32 different coatings were selected and applied by brush according to the manufacturer's instructions. A minimum of 2 and a maximum of 4 coats were applied to each plate.

The plates were supported in racks (Figure 1) made of reinforcing rod with welded joints. The racks were immersed in settled sewage in open channels conducting the effluent from the primary clarifiers at the Joint Meeting sewage treatment plant of Plainfield, N. J. The period covered in these studies was from February 14 to March 27, 1952. Plates of each type were sampled at weekly intervals for 6 weeks. A special sampler (Figure 2) was used to scrape the growth from 1 sq. dm. of plate surface into a con-

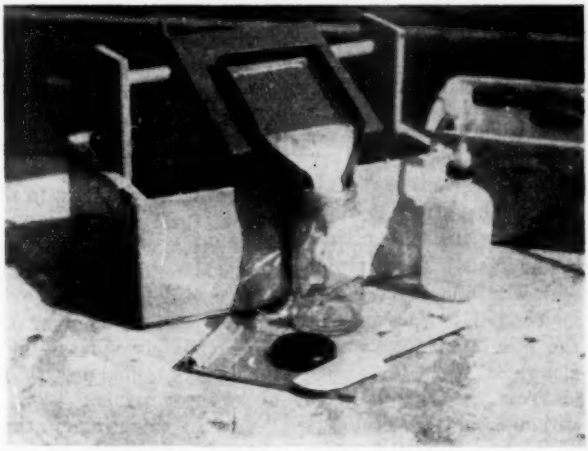

FIGURE 2.—Special 1-sq. dm. sampler used for scraping slime growth from test plate surfaces.

tainer. The dry weight of the growth was determined. The effect of coating and biological inhibitors was evaluated from the amounts of slime on a dry weight basis, expressed as milligrams per square decimeter, as compared with similar values for untreated concrete controls.

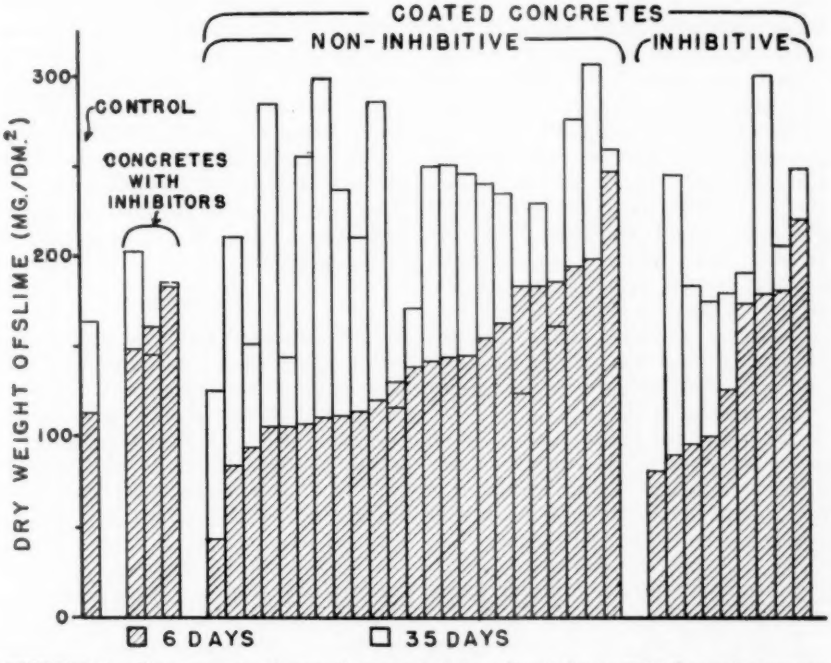

FIGURE 3.—The amounts of growth on test plates after 6-day and 35-day submergence in sewage.

Results

The amounts of growth on the test plates after the first 6 days and after 35 days are presented graphically in Figure 3. The 6-day results were selected to show the initial inhibitory action, if any, of the various materials used, whereas growths after 35 days were selected to show the longer time effect of these materials. The samples taken after 6-week immersion could not be used for comparison, because in many cases the weight of the growth caused it to slough off when the plates were removed from the channel. It should be mentioned that the accumulation between the first and fifth weeks was not one of steady increase, but showed fluctuations. This can be interpreted only on the basis of sloughing off the growth at intervals, followed by regrowth. A more frequent, possibly daily, sampling, as has been used with microscopic slide surfaces in other studies, gives a more precise picture of these cyclic growths and sloughs. Consideration of the average amounts of growth during the entire period would also be misleading for the same reason.

Results presented in Figure 3 are grouped according to the nature of the material used. In the first group are the three inhibitors incorporated in the concrete; namely, the 1 and 5 per cent copper oxide and the antibacterial cement. In the second group are presented 23 coatings which do not contain special inhibitors, and in the third group 9 coatings with inhibitors. The names of these preparations are given in the same order in Table I.

The individual preparations in each group are given in the ascending order of the amount of growth during the first sampling period of 6 days, and are compared with the control test plates. On the basis of a special study, the variations between duplicate plates were in the order of 5 per cent.

Figure 3 shows that in none of the concrete plates incorporating an inhibitive agent was the initial growth (after 6 days) lower than the control. The quantity of growth after 35 days in one instance in this group was somewhat lower than the growth on the control plate after a similar period of immersion, but this may be due to sloughing rather than to the inhibiting agent.

Of the 23 coatings without inhibitors, only 3 showed appreciably less (at least 10 per cent) growth during the first 6 days than the control plates. 7 were approximately equal to the control, and the rest contained growths considerably above the controls.

The three coatings in this group that showed retardation of growth during the initial period had increased accumulations after 35 days. On two of these the quantity of growth was still less than that of the control.

Only 4 of the 9 coatings containing an inhibitive agent were significantly (at least 10 per cent) below the control after 6 days, and none after 35 days. Of the coatings which during the initial period were about equal to the control, only 1 was slightly lower than the control after 35 days, all the rest being decidedly higher. The paints which initially gave decidedly higher amounts of growths had, with two exceptions, also considerably higher growths than the control at the end of this test period.

Discussion

It is apparent from the results that some of materials tested had an initial retarding action, which was overcome after a relatively short period of immersion. None of them manifested a short- or long-time inhibitive effect. A period of 5 or 6 weeks is rather short in the life of a concrete structure in contact with sewage, industrial waste, or other polluted waters. Also, the growth accumulation is not one of ascending order with increased time of contact or submergence, but is subject to intermittent sloughs. It is readily

TABLE I.—Effect of Protective Coatings and Antibacterial Concrete on Slime Growth (Slime Weights in Mg. per Sq. Dm.)

Test Surface	Days Immersed						
	6	14	21	28	35	Av.	42
Control	113	168	88	120	164	131	394
(a) Concretes with Inhibitors							
Antibact. cement	149	179	103	108	203	148	415
1% CuO cement	162	364	119	226	146	203	465
5% CuO cement	183	229	104	160	186	172	517
(b) Coatings without Special Inhibitors							
Neobon	43	66	86	105	126	85	—
Koraloy 470	84	127	89	60	211	114	486
Pyroflex	94	87	80	117	152	106	—
Ucilon E	106	169	82	206	284	169	—
Zerok 110	106	223	69	105	144	129	—
Ampreg E	107	278	110	91	256	168	606
Inertol std. thick	111	221	119	208	298	191	—
Alkaloy 550	112	104	93	111	237	131	492
Tornesite	114	169	113	126	211	147	—
Panoflam	120	138	109	147	287	160	—
Ucilon G	131	36	80	134	116	99	—
Zerok 101	138	162	119	172	172	153	—
Bitumastic	142	222	101	199	250	183	—
Tygon	144	225	98	99	251	163	—
Amplast 60	145	283	85	224	247	197	—
Inertol std.	155	204	89	225	240	183	—
B. resin	163	229	119	162	235	182	—
Zerok 125	183	168	74	114	124	133	438
Heresite	183	183	94	119	229	162	—
Torex	186	144	104	161	162	151	—
Acid caustic bond	194	140	120	138	277	174	—
Zerok 115	198	121	71	170	307	173	—
Ucilon P	247	317	78	104	259	201	—
(c) Coatings with Inhibitors							
Zerok 115	81	43	97	129	—	87	—
Alkaloy 550	90	217	98	113	250	154	615
Ampreg E	96	174	108	102	183	133	457
Koraloy 470	100	201	94	101	175	134	513
Neobon	126	288	79	80	179	150	462
Zerok 125	173	75	69	105	191	123	515
Zerok 101	178	72	114	142	300	161	—
Zerok 110	182	159	95	88	207	146	—
Amplast 60	220	229	76	181	248	197	—

evident that a new surface free from growths and containing a potent inhibiting agent may, at first, prove effective in checking the growth. Unless the inhibiting agent can effectively check growths permanently, however, the biological coating formed will insulate the inhibiting agent against further growth, since new growth can take place over the surface of the biological slime rather than against the concrete surface or the protective coating. It

also follows that, unless the sloughing removes the biological slime completely, the inhibitive agent in the coating or concrete cannot be effective in checking new growth. It is not likely that sloughing results in the complete removal of all slime, but leaves some growth, which reduces the effectiveness of the inhibiting agent to prevent regrowth after slough.

Coatings, in general, with or without inhibitors have been considered effective in reducing slime accumulation in still another way; namely, by exposing smooth surfaces that might make it difficult for the slime-forming organisms to attach themselves and to accumulate. Extensive experiments using surfaces of different degrees of smoothness, varying from glass to glazed tile, transite, and concrete, show no evidence that, with the possible exception of the initial period, the degree of smoothness or roughness of a surface has any effect on the quantity of growth.

Summary and Conclusions

Concrete test plates with and without inhibitors incorporated in them, and concrete plates coated with paints with and without special inhibitors, were submerged in an open channel carrying settled sewage. The amount of growth formed was determined by sampling the slime from one of the six complete series of test surfaces at weekly intervals for six weeks. The results are expressed as milligrams of dry weight per square decimeter of surface area.

The results warrant the following conclusions:

1. The accumulation of growth on all types of surfaces with or without protective coatings or inhibitors is not continuous, but is subject to intermittent reductions due to sloughing.

2. Complete inhibition of growth was not obtained with any of the 35 coatings and growth inhibiting materials tested, even for short periods.

3. Initial retardation of growths was exhibited with a few of the materials tested. In most instances this retardation was obliterated after longer periods of submergence.

4. Most of the materials tested showed neither a short-time nor a long-time effect in retarding slime accumulations.

5. It appears that unless an inhibiting material is used which completely inhibits growth, the formation of a slime coating will reduce the effectiveness of the inhibiting agent and, therefore, cannot have a permanent retarding influence.

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A COMPARATIVE STUDY OF DERIVATION PROCEDURES FOR B.O.D. VELOCITY CONSTANTS

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The large number of calculations of velocity constants entailed in a study of the relative merit of different types of "seed" for the biochemical oxygen demand determination made a simple and rapid method for determination of these constants highly desirable.

The "moments" method, suggested by Moore *et al.* (1) appeared to satisfy these criteria, provided its applicability was as good for general use as the data submitted in the original article indicated. Since the original data included a relatively narrow range of rate constants, the present study has extended this range to include those normally encountered in a wide variety of samples. In addition, several different types of systems are included, such as undiluted river water, dilutions of domestic sewage, and dilutions of a standard nutrient consisting of 150 p.p.m. each of cp. glucose and glutamic acid.

The biochemical oxygen demand data were obtained following the procedures of "Standard Methods" (2) using 10-day series with observations at 48-hour intervals in most cases, 24-hour intervals in others. The work involving the standard nutrients was a modification of the work presented by Sawyer *et al.* (3). The primary modification in procedure consisted of using a mixture of 150 p.p.m. glucose and 150 p.p.m. glutamic acid instead of 300 p.p.m. of either one as the standard nutrient.

The biochemical oxygen demand velocity constant calculation methods used for comparison with the values obtained by the "moments" method (1) were the Thomas (4) "slope" method as modified by Ettinger (5), and the Reed-Theriault (6) "least squares" method. The slope method has been the standard procedure at the Environmental Health Center for several years. The Reed-Theriault procedure, however, is the basic method, making no assumptions except for a trial value for k, which is either accepted or rejected on the basis of the subsequent calculations. It requires a great deal of time for the calculation, but has a degree of precision that is unquestioned.

Preliminary Work

In the preliminary work on this study, 117 series using dilutions of the glucose-glutamic acid standard nutrient with various seed materials were subjected to velocity constant calculation by both the slope and moments methods. The B.O.D. series were based on 2-day intervals for 10 days. The assembled data are given in Tables I, II, and III. Since approximately two-thirds of the 117 series had rate constants by the moments method within a range of 0.114 to 0.190, the data presented were selected by reporting every third series, or in some cases every fifth series, to reduce the number of individuals in the tables.

Table I includes the series having low rate constants. The rates (values of k) calculated by the moments method tend to exceed those obtained by the slope method. The difference between the values (slope minus moments) was negative for 10 of the first 11 values. Above a moments method rate of approximately 0.125, this trend disappeared. Ultimate B.O.D. (L) results were in good agreement except on those

TABLE I.—Comparison of Constants by Slope and Moments Methods for B.O.D. Series Having Low Rates

Series No.	Values of k			Values of L		
	Slope	Moments	Diff.[1]	Slope	Moments	Diff.[1]
1	0.073	0.039	0.034	360	513	−153
2	0.052	0.096	−0.044	355	257	98
3	0.068	0.105	−0.037	321	268	53
4	0.095	0.112	−0.017	277	259	18
5	0.104	0.112	−0.008	297	285	12
6	0.097	0.113	−0.016	269	246	23
7	0.096	0.114	−0.018	261	244	17
8	0.087	0.114	−0.027	270	243	27
9	0.111	0.117	−0.006	271	262	9
10	0.101	0.118	−0.017	285	266	19
11	0.113	0.119	−0.006	270	258	12
12	0.141	0.121	0.020	233	234	− 1
13	0.122	0.121	0.001	261	261	0
14	0.115	0.122	−0.001	277	267	10
15	0.137	0.124	0.013	271	268	3
16	0.139	0.124	0.015	263	266	− 3
17	0.139	0.125	0.014	248	260	−12
18	0.120	0.125	−0.005	246	236	10
19	0.103	0.125	−0.022	274	256	18
20	0.121	0.125	−0.004	252	246	6

[1] Value by slope method minus value by moments method.

TABLE II.—Comparison of Constants by Slope and Moments Methods for B.O.D. Series Having Intermediate Rates

Series No.	Value of k			Value of L		
	Slope	Moments	Diff.[1]	Slope	Moments	Diff.[1]
21	0.137	0.128	0.009	265	261	4
22	0.123	0.129	−0.004	251	246	5
23	0.131	0.132	−0.001	252	245	7
24	0.140	0.133	0.007	262	261	1
25	0.148	0.134	0.014	269	270	−1
26	0.145	0.135	0.010	257	257	0
27	0.149	0.138	0.011	269	269	0
28	0.151	0.138	0.013	262	262	0
29	0.153	0.140	0.013	261	260	1
30	0.138	0.141	−0.003	232	229	3
31	0.148	0.142	0.006	278	274	4
32	0.156	0.142	0.014	257	257	0
33	0.148	0.144	0.004	252	251	1
34	0.161	0.144	0.017	259	261	−2
35	0.136	0.144	−0.008	234	228	6
36	0.157	0.145	0.012	258	258	0
37	0.160	0.148	0.012	254	252	2
38	0.142	0.148	−0.006	253	244	9
39	0.163	0.148	0.015	244	247	−3
40	0.165	0.149	0.016	259	259	0

[1] Value by slope method minus value by moments method.

TABLE III.—Comparison of Constants by Slope and Moments Methods for B.O.D. Series Having High Rates

Series No.	Value of k			Value of L		
	Slope	Moments	Diff.[1]	Slope	Moments	Diff.[1]
41	0.162	0.152	0.010	258	255	4
42	0.172	0.155	0.017	268	268	0
43	0.176	0.158	0.018	239	241	−2
44	0.169	0.160	0.009	232	230	2
45	0.189	0.165	0.024	260	262	−2
46	0.182	0.167	0.015	236	234	2
47	0.186	0.169	0.017	241	240	1
48	0.199	0.171	0.028	217	219	−2
49	0.190	0.172	0.018	231	229	2
50	0.191	0.175	0.016	233	232	1
51	0.195	0.178	0.017	254	252	2
52	0.201	0.180	0.021	242	242	0
53	0.208	0.186	0.022	241	240	1
54	0.214	0.189	0.025	227	227	0
55	0.209	0.192	0.017	235	230	5
56	0.196	0.196	0	238	235	3
57	0.218	0.200	0.018	232	229	3
58	0.234	0.208	0.026	236	234	2
59	0.247	0.211	0.036	203	204	−1
60	0.254	0.215	0.039	194	194	0
61	0.237	0.218	0.019	225	222	3
62	0.321	0.243	0.078	235	239	−4

[1] Value by slope method minus value by moments method.

series with the lowest velocity constants.

Table II presents the data for the two methods at intermediate rates. In this group, the rates calculated by the slope method were higher in 15 of 20 series, although the differences were small in most cases. Very good agreement was obtained on values of L with the two methods.

Table III is a compilation of similar data for those series having high rate constants. This group shows a marked reversal of the tendency indicated in Table I, where the moments method resulted in higher rate values. In this group there is one series with the same rate by both methods of computation, otherwise the slope method resulted in a higher rate for each series. In addition, the higher the rate the greater the differential between the two rate factors. As in Table II, there was little difference between the calculated values of L.

Further Studies

From the data in these three tables the tendency of the slope method for extreme values of k is quite evident. In the range of values of k from approximately 0.12 to 0.15 the two methods are nearly equal; below this range the slope method results in the lower value of k. Above k values of 0.15, the slope method results in the higher value of k.

After obtaining these data a representative group of the series was selected for comparison with the results obtained by the Reed-Theriault method (Table IV). Samples were selected which represented a wide range of velocity constants. In addition to the comparison with Reed-Theriault k and L values, derived constants obtained by each method were used in the formula $Y_t = L(1 - 10^{-kt})$ to obtain values of Y, or the B.O.D. exerted at time t. The calculated values were then compared

TABLE IV.—Comparison of B.O.D. Constant Derivations by Slope, Moment, and Reed-Theriault Methods

Series No.[1]	Value of k			Value of L			Sum of Squares[2]		
	Slope	Moments	Reed-Theriault	Slope	Moments	Reed-Theriault	Slope	Moments	Reed-Theriault
1D	0.021	0.034	0.032	68	20.5	23.5	1,838,000	4,720	38,000[3]
2U	0.037	0.046	0.040	7.35	6.55	7.19	1,968	1,876	1,050[3]
3D	0.035	0.048	0.044	18.7	15.5	17.2	7,728	6,200	5,600[3]
4U	0.051	0.058	0.055	8.40	7.75	8.00	354	304	288[3]
5U	0.076	0.076	0.074	4.98	5.09	5.16	220	130	144[3]
6U	0.080	0.078	0.078	3.99	4.06	3.94	728	816	564[3]
7U	0.082	0.081	0.078	8.41	8.44	8.56	936	856	244[3]
8U	0.076	0.081	0.080	3.33	3.23	3.26	168	160	153[3]
9D	0.096	0.114	0.110	261	244	247	548	536	532
10D	0.137	0.124	0.127	271	268	281	304	205	217
11D	0.139	0.125	0.127	248	260	259	138	52	48
12D	0.159	0.137	0.138	221	228	226	264	112	136
13D	0.153	0.140	0.143	261	260	259	772	552	540
14D	0.128	0.149	0.146	242	229	230	624	516	532
15D	0.163	0.148	0.148	244	247	246	136	40	40
16D	0.173	0.154	0.157	254	255	255	464	316	296
17D	0.189	0.165	0.167	220	262	262	376	160	156
18D	0.180	0.172	0.170	246	241	243	416	188	176
19D	0.199	0.172	0.173	247	249	249	452	200	168
20D	0.199	0.171	0.174	217	219	219	256	48	48
21D	0.219	0.179	0.182	252	258	257	552	220	220
22D	0.221	0.191	0.193	223	228	228	124	28	52
23D	0.229	0.189	0.202	221	221	220	296	44	4
24D	0.321	0.243	0.283	235	239	237	452	168	246
25D	0.341	0.277	0.319	238	237	232	992	1,052	724

[1] D indicates a series based on a diluted sample; U indicates an undiluted sample.

[2] The sum of squares data in some cases indicate a higher value for the Reed-Theriault than for the moments method. This was usually associated with erratic initial or final B.O.D.'s in the series.

[3] B.O.D. value multiplied by 100 to expand sum of squares values to correspond with the range of the remainder of the data.

with observed B.O.D. values reported for the appropriate time interval.

This procedure resulted in five comparable values for B.O.D. on even-numbered days in the 10-day series. The differences between the observed and calculated values were expressed as a sum of squared differences, hereafter designated the "sum of squares." The resulting value was used as a parameter for the degree of fit obtained for the rate and ultimate B.O.D. by a given method of derivation of the constants. When using this parameter a 5 per cent deviation between observed and calculated B.O.D. on a series with a value of $L = 250$ would result in a sum of squares of approximately 600. In several series where erratic observed B.O.D. values were obtained, a low sum of squares could not be obtained by any method of derivation for the constants. In this case, the method with the lowest sum of squares was accepted as the better method.

Table IV indicates that the moments method rates were in better agreement with Reed-Theriault rate values in 84 per cent of the calculations. In the range normally encountered for k values in B.O.D. work the agreement in favor of the moments method was appreciably in excess of 84 per cent. Values of L as obtained by all three methods were in good agreement in nearly every case except when extreme

values for the rate constants were obtained.

The use of the slope method of calculation is affected to a greater extent by very low rate constants. For example, in Item 1, Table IV, where the $k = 0.021$ by the slope method, the value of L is unduly influenced toward a high value. In this case, the value of L is approximately three times that obtained by either the Reed-Theriault or the moments method.

Relatively high k values, such as Item 25, Table IV, apparently are out of the range where agreement in results is possible. In this case, the Reed-Theriault values were intermediate in comparison with those of the slope and moments methods. Since values of k in excess of 0.28 are relatively rare, this change in relationship between the results by the three methods is not of much practical importance.

The data on sum of squares (Table IV) show the same advantage for the moments method over the slope method when compared with the Reed-Theriault procedure.

One significant factor that appeared in these data was the difference in behavior of the samples of undiluted river water and those of diluted samples of river water or waste. On the undiluted river waters, the values of k and L were in good agreement by all of the three methods of derivation. However, on diluted samples the moments method was a better approximation to the Reed-Theriault values. The difference in behavior was attributed to the initial lag in the diluted samples as the system acclimated itself to new conditions. This acclimatization frequently is accompanied by abnormal or erratic values for the initial B.O.D.'s in the series. In the slope method of evaluating rate constants, the initial values have much greater effect on the results obtained in the calculation than is the case in the moments method. This factor is one of the primary reasons why a better approach to Reed-Theriault values is obtained by the moments method. In B.O.D. series, the initial observed values are the most likely to present erratic behavior due to lag. Therefore, if a greater weight is given to these, as in the slope method, a greater deviation

TABLE V.—Comparison of B.O.D. Constants Derived at 24- and 48-Hr. Intervals

Series No.[1]	Value of k		Value of L		Sum of Squares[2]	
	Slope	Moments	Slope	Moments	Slope	Moments
1A	0.065	0.073	549	517	60	40
1B	0.074	0.075	518	512	96	40
2A	0.092	0.111	546	507	1,352	1,608
2B	0.107	0.100	519	532	1,452	1,360
3A	0.139	0.141	306	302	128	144
3B	0.160	0.142	300	303	336	120
4A	0.144	0.156	337	330	476	368
4B	0.179	0.159	321	325	656	348
5A	0.165	0.167	244	244	120	128
5B	0.171	0.152	250	252	244	72
6A	0.184	0.169	219	223	388	320
6B	0.164	0.152	231	233	300	212
7A	0.199	0.201	385	385	248	262
7B	0.201	0.183	391	389	508	84
8A	0.225	0.216	218	219	440	420
8B	0.235	0.213	218	219	508	400

[1] A indicates a series calculated for k and L on the basis of 24-hr. intervals for 10 days; B indicates the same series, but using 48-hr. intervals only for calculation of k and L.

[2] Sum of squared differences calculated for even-numbered days in all series.

is likely to be found in the derived constants than is the case with the moments method.

Since the use of a 10-day series at 48-hr. intervals may have an effect upon the application of the various methods, several series were checked at 24- and 48-hr. intervals. The data (Table V) indicate a relatively small difference in the values of k and L obtained by a given derivation with the two intervals. This is in agreement with a similar comparison made by Ruchhoft *et al.* (7). However, certain trends are indicated by the differences encountered at the two time intervals. The rate, or value of k, obtained by the slope method for the two time schedules was higher on the 48-hr. interval in 6 of 8 series. The moments method resulted in a lower value of k for the 48-hr. interval in 5 of 8 series. The average difference in rate for the slope method was 0.015, compared to 0.008 for the moments method. The largest difference between rates for the two time schedules was 0.035, with 5 of 8 values greater than 0.01 for the slope method. The corresponding values for the moments method were 0.018 for the largest difference, with 4 of 8 greater than 0.01. The two time schedules affected an average difference in L by the slope method of 13, and a highest difference of 31. The average difference in L by the moments method was 7, with the high deviation of 25. Both high values were on series 2.

These data indicate that the moments method is not affected as much as the slope method by a change in time on the same set of data. Extreme differences and average difference are less for both k and L when calculated by the moments derivation.

Although the greater part of this study has been concerned with the precision of k and L value derivations from data, a very important difference in these procedures lies in the relative ease of application. The Reed-Theriault method is the most complex and time consuming. A minimum of 30 min. for each trial is necessary to complete the necessary operations, which may have to be repeated with new trial values if the correction is too large. (In the calculations for Table IV, the value was accepted if the correction was in the third decimal place.) The slope method requires approximately 10 min., whereas the moments procedure can be completed in about 2 min. A calculation by the moments method is easily checked for arithmetic errors, which is not the case for the other two procedures. The construction of a graph for the time sequence for the moments method is rather complex; however, this is not a significant deterrent against the moments method, because relatively few different time sequence schedules are used and the graphs are easily reproduced.

Conclusions

1. From the data obtained in this study, the velocity constants and L values obtained by the moments method were a better approximation to Reed-Theriault values than were those obtained with the slope method. The "sum of squares" parameter also indicated preference for the moments method as compared to the slope derivation.

2. Time, manipulation, and simplicity of calculations for k and L definitely favor the use of the moments method.

3. The derivation of k and L on a given sample affords a more complete characterization of biochemical oxidation of a waste than is possible without these parameters.

4. The moments method of derivation applied to B.O.D. observations at 48-hr. intervals for a 10-day period is recommended as a satisfactory procedure for wider application in the study of the reaction.

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VITAMIN B12 PROJECT ANNOUNCED

Under an exclusive contract with the Milwaukee Sewerage Commission, the Chicago engineering firm of Vern E. Alden Company is to produce vitamin B12 concentrate from Milorganite, the dried and disinfected activated sludge from the Commission's sewage treatment plant.

The contract calls for construction of a pilot plant in the Chicago area by August 16, 1953, and operation for three months to extract the vitamin on a small scale at the cost of about $25,000. Object of the pilot plant will be to double check on the patented process developed by the Commission's research consultants for extraction of the valuable vitamin concentrates from Milorganite.

After sufficient B12 concentrate has been produced at the pilot plant, the Alden Company will demonstrate it to potential users and make a market survey. According to the contract, the Company will have one year in which to build and operate the pilot plant and prove the market before it must decide whether to go ahead with construction of a $1,000,000 plant for production of B12 concentrate at the sewage treatment plant site.

The Commission is to get 35 per cent of net profits before taxes on earnings of the Company from processing the 70,000-ton annual output of Milorganite. The full-scale recovery unit would be tapped into the present fertilizer processing plant between the drying room and the weighing and bagging building. Returns to the Commission from the project are expected to be as high as "several hundred thousand dollars" the first year of commercial operation, with bright prospects for a higher return as markets for the vitamin materials expand. At present, Milorganite sales yield a gross revenue of about $2,400,000, or about 60 per cent of the cost of operating the entire sewage treatment plant.

The B12 concentrate is valuable in animal feeds as a supplement affecting growth, particularly in hogs and poultry. It can be marketed either as a 40 per cent aqueous solution or as a spray dried powder. On a dry basis the concentrate would contain in excess of 20 mg. of vitamin B12 per pound of solids, as compared with the 1.5 mg. per pound standard set by the Association of American Feed Control Officials.

RADIOACTIVE EFFECTS ON THE B.O.D. OF SEWAGE

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Radioactive wastes are discharged in increasingly large quantities into plumbing and sewer systems, sewage treatment plants, and receiving bodies of water. Sanitary engineers and others charged with safeguarding public health have been concerned about the potential contamination hazard, the effects on biochemical oxidation, and the ultimate disposal of the wastes.

From the early reports by Gorman and Wolman (1)(2) and Western (3), outlining the character of wastes from nuclear fission operations, various phases have been under investigation. Newell and Christenson (4) enumerated available methods of waste disposal and indicated their adaptability to treatment of radioactive wastes. The application of biological treatment methods to provide an economical and practical solution was described by Ruchhoft *et al.* (5)(6)(7) and the results based on intensive studies are reassuring. Concentration of the wastes by evaporation as a feasible method towards ultimate disposal was shown by McCullough (8) and Browder (9). Among other possible treatment procedures, ion exchange was studied by Ayres (10), and coagulation and carrier precipitation methods were applied both at Los Alamos (11) and at Oak Ridge (12).

Furthermore, the effects of increasing quantities of radioisotope wastes (I^{131}) discharged by hospitals to sewers were evaluated (13); studies on the uptake of radiophosphorus (P^{32}) by bacterial slimes in traps, sinks, and drains were conducted at the Johns Hopkins University (14); and handling and disposal of radioactive wastes in public sewers were considered by Parkhurst (15) and Kittrell (16) more recently.

Object of Study

The object of this study was to determine the effects of radioactive phosphorus (P^{32}) and iodine (I^{131}) on both the first and second stages of biochemical oxidation of sewage, as part of the broader program previously outlined. An evaluation of the effects of P^{32} on the first stage was reported earlier (17). The biochemical oxidation reaction measured by the B.O.D. test was chosen because of its fundamental importance in sewage treatment processes and in the final assimilation of organic matter during self-purification in streams.

The course of biochemical oxidation of sewage and organic wastes is described by a reaction velocity and other parameters which lend themselves to statistical analysis to evaluate any real effects.

The two isotopes were chosen because they comprised approximately 70 per cent (18) of all isotope shipments from Oak Ridge and because they provide different types of radiation exposure on the microbiological organisms associated with sewage and streams. Radiophosphorus (P^{32}), a pure beta emitter, participates in the metabolism of the organisms responsible for the oxidation of the organic matter in sewage, whereas radioiodine (I^{131}), a beta and gamma emitter, is regarded as not being directly involved in the metabolism of these organisms.

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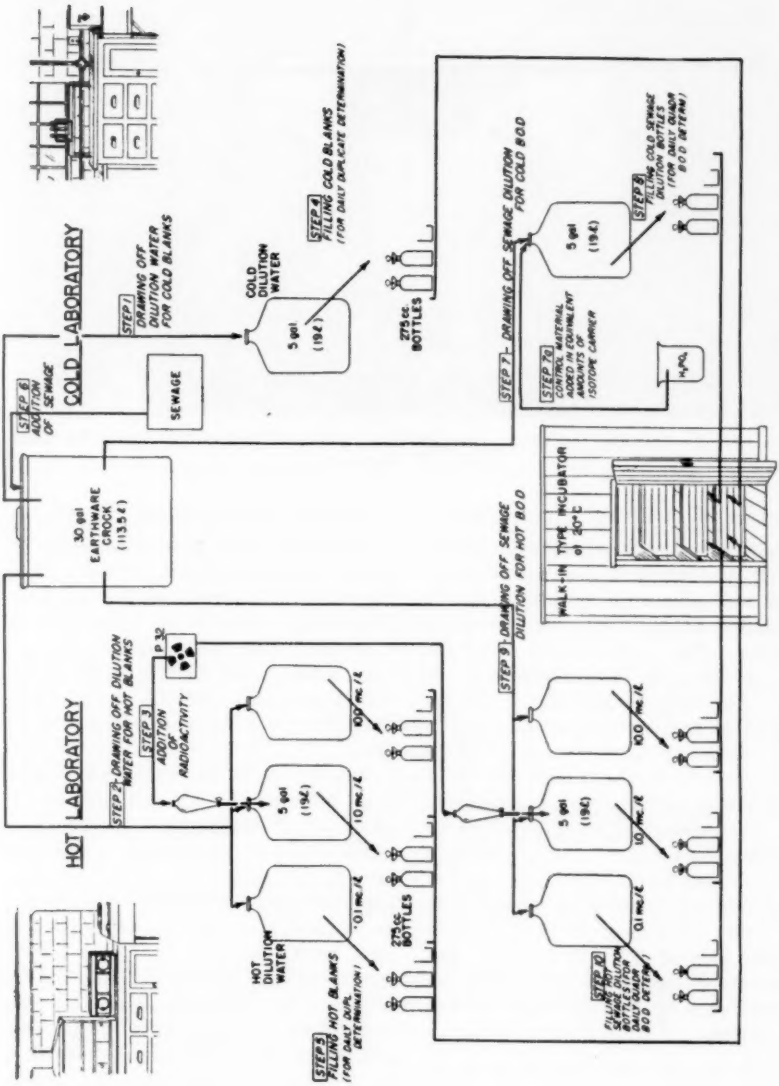
COLD LABORATORY
HOT LABORATORY
STEP 1 DRAWING OFF DILUTION WATER FOR COLD BLANKS
STEP 2 DRAWING OFF DILUTION WATER FOR HOT BLANKS
STEP 3 ADDITION OF RADIOACTIVITY
STEP 4 FILLING COLD BLANKS (FOR DAILY DUPLICATE DETERMINATION)
STEP 5 FILLING HOT BLANKS (FOR DAILY DUPLICATE DETERMINATION)
STEP 6 ADDITION OF SEWAGE
STEP 7 DRAWING OFF SEWAGE DILUTION FOR COLD BOD
STEP 7a CONTROL MATERIAL ADDED IN EQUIVALENT AMOUNTS OF ISOTOPE CARRIER
STEP 8 FILLING COLD SEWAGE DILUTION BOTTLES (FOR DAILY DUPLICATE BOD DETERMINATION)
STEP 9 DRAWING OFF SEWAGE DILUTION FOR HOT BOD
STEP 10 FILLING SEWAGE DILUTION BOTTLES FOR DAILY DUPLICATE BOD DETERMINATION
SEWAGE
COLD DILUTION WATER
HOT DILUTION WATER
30 gal EARTHWARE CROCK (11354)
5 gal (19ℓ)
275cc BOTTLES
P 32
WALK-IN TYPE INCUBATOR at 20°C
100 mc/ℓ
10 mc/ℓ
1·0 mc/ℓ
0·1 mc/ℓ
H2SO4

FIGURE 1.—Flow diagram of experimental procedure.

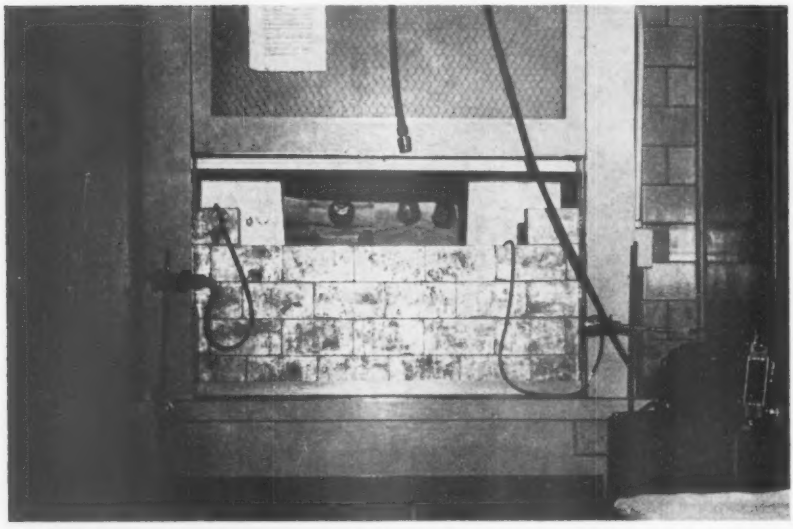

FIGURE 2.—Rebuilt laboratory hood with lead shielding and mirror for performing initial I^{131} dilutions.

Levels of Activity Investigated

The range of concentrations of radioactivity applied to the sewage were selected well above the maximum levels of disposal likely to be encountered in practice. The purpose was to establish any effects at such higher concentrations as may be caused by the accumulation and concentration of radioactive materials in a sewer or in a stream (19).* In the studies described herein the initial activities ranged from 10^{-2} to 10 millicuries (mc.) per liter of radiophosphorus (P^{32}) and radioiodine (I^{131}). These levels compare with the tentatively established concentrations of 10^{-4} mc. per liter of P^{32} and 5×10^{-4} mc. per liter of I^{131} (20). They are recommended maximum concentrations for discharge by an institution into a main sewer.

* At the Hanford AEC Works it was found that "plankton can accumulate phosphorus (stable and radioactive alike) in concentrations 200,000 times that of surrounding water, algae as much as 50,000, and fish over 100,000. Phosphorus can be transmitted and concentrated through biological chains . . . from water into algae, etc." (19).

General Experimental Procedure

Relatively weak domestic sewage collected from a residential section of the Bronx, N. Y., served as the substrate. The sewage was cotton filtered to remove large suspended solids. The optimum sewage dilution for the first stage was 4 per cent and 2.5 per cent for second-stage studies extending to 30 days.

The technique employed in this study was to measure simultaneously the progress of biochemical oxidation of plain sewage and sewage dosed with several concentrations of radioisotopes. Equal amounts of stable isotope, acting as "carrier" in the radioisotope solution, were added to the plain sewage serving as the control. Thus, the addition of the radioisotope was the only real difference between them. The oxygen uptake was determined daily from an average of quadruplicate samples for each concentration. (Techniques of diluting the original isotope solution and dosing of the sewage samples under shielded laboratory conditions were reported previously (17).) Inasmuch

as the first stage of the B.O.D. reaction is generally of more immediate interest, these investigations were mainly devoted to it. The number of laboratory runs devoted to second-stage oxidation were much fewer and the data are scantier.

A flow diagram of the laboratory procedure for B.O.D. determinations is shown in Figure 1. It may be observed that the procedures for both plain sewage and radioactive sewage (referred to as "cold" and "hot") were identical, except for the addition of the isotope, steps 3 and 9a. This flow diagram also shows that samples of plain sewage were stored in the same incubator with the radioactive samples, the former being shielded from irradiation. Plexiglass ¼ in. thick shielded against the emission of beta particles from P^{32} and later, when I^{131} was used, ⅛-in. lead sheathing protected the plain sewage from the electromagnetic gamma rays. The design, layout, and operation of the laboratory for handling radioactive phosphorus has been previously described (21) and only minor modifications were needed to handle I^{131}. Figure 2 shows the rebuilt laboratory hood with 2-in. thick lead bricks and mirror to perform the initial dilution of I^{131}.

Measurements of nitrite and nitrate nitrogen were obtained as supporting data of any effects of radioactivity on the course of biochemical oxidation. All determinations were carried out colorimetrically on a Beckman quartz spectrophotometer, model D.U. Cells of the 100-mm. size were needed to detect the small amounts of nitrogen compounds formed.

Some limited studies of possible effects due to radioactivity on the bacterial density in the sewage were also

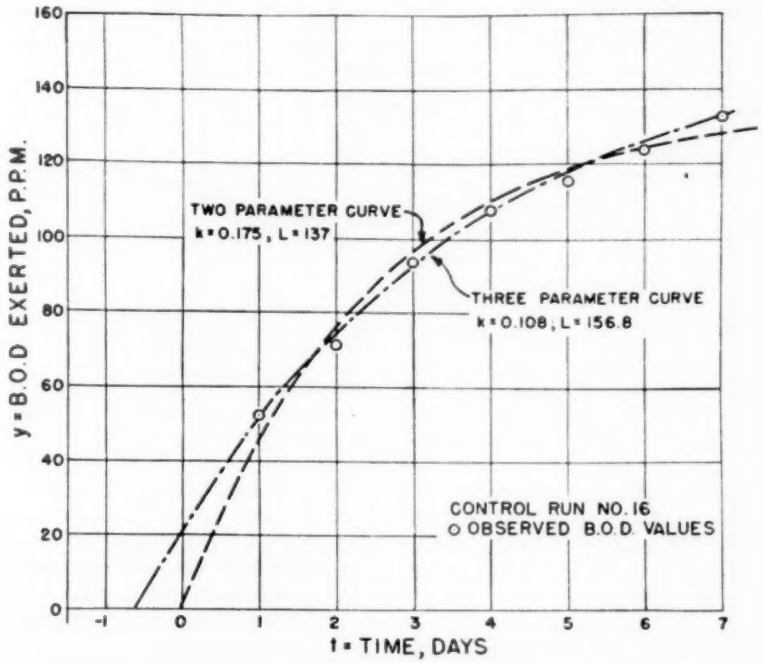

FIGURE 3.—Two-parameter curve and three-parameter curve ($t_o = -0.589$) fitted to the same B.O.D. data.

undertaken. The bacteriological examination consisted of plate counts on tryptone glucose agar as described in "Standard Methods" (22).

Analysis of Experimental B.O.D. Values

The composite reactions involved in the oxidation of the complex organic matter in sewage are generally represented by a first-order reaction for the first-stage oxidation as follows:

$$y = L\,(1 - 10^{-k\,t}) \quad \ldots\ldots (1)$$

in which y is the amount of oxygen utilized in time t, (B.O.D. in p.p.m.); L is the total amount of oxidizable material initially present (total first-stage B.O.D. in p.p.m.); and k is the reaction velocity constant. This equation usually provides a good fit to the data observed during first-stage oxidation of fresh sewage. It properly assumes that at $t = 0$, the value of $y = 0$ is a valid point used for the curve fitting.

The second stage of biochemical oxidation may also be adequately represented by an equation of the unimolecular type with the properly fitted lag period, as suggested by Thomas (23). Occasionally, it has been difficult to obtain a close fit to first-stage oxidation data by use of a curve which goes through the origin. If there is a high initial oxygen demand or a retardation in the oxidation process, a better fit to such data may likewise be obtained by

$$y = L\,[1 - 10^{-k(t - t_0)}] \quad \ldots\ldots (2)$$

in which t_o is the lag period. In fitting a curve of this type to the data, the origin is not used as a valid point. Positive values of this lag may be interpreted as indicating that oxygen utilization does not immediately pro-

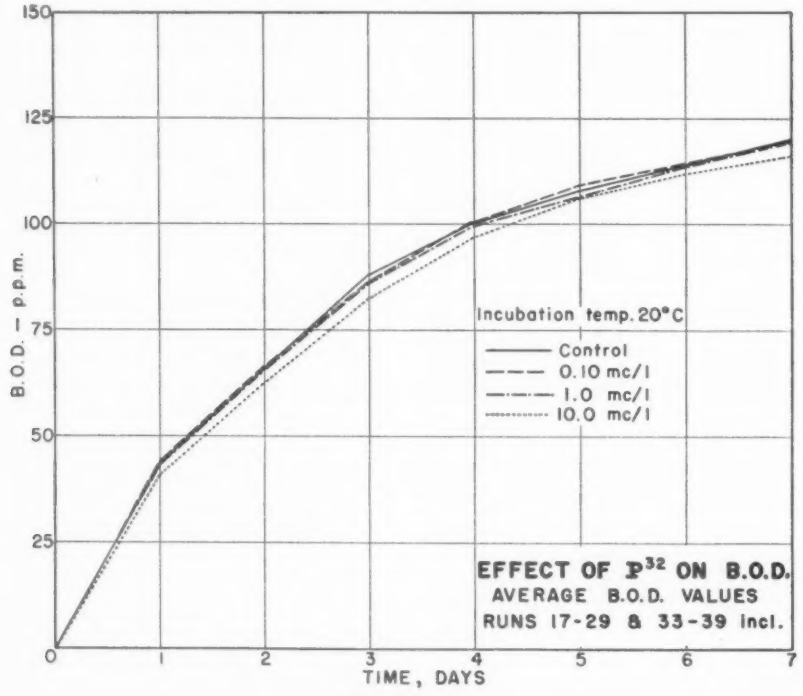

FIGURE 4.

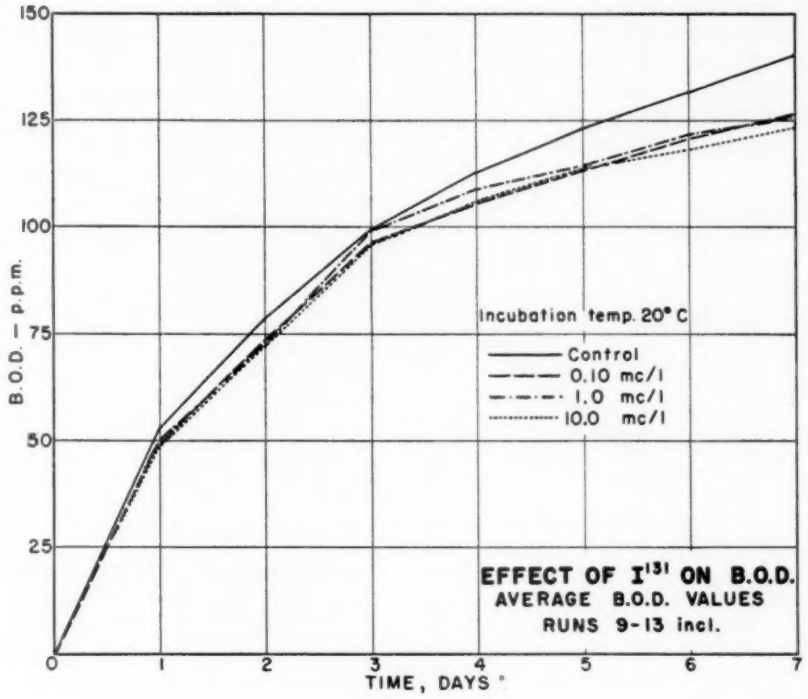

FIGURE 5.

ceed at the rate which it ultimately reaches. The presence of toxic agents or initial lack of balanced sewage oxidation organisms may be responsible for this behavior. Negative values of t_0, although difficult to interpret, may be viewed as indicative of an initial oxygen demand satisfied almost instantaneously.

Various methods have been proposed for calculating the parameters of the curve of best fit to a given set of B.O.D. data, the most accurate being the "method of least squares." The parameters of the B.O.D. curve were computed in this study by the "method of moments" (24), by which the curve is fitted to the data so that the moments of selected points on the curve about the origin are equal to the corresponding moments of the observed data. The moment methods give results that compare well with the least squares method and are recommended because of the simplified computations.

A "two moment method" is used for fitting a two-parameter curve (k and L) and a "three moment method" for fitting a three-parameter curve, (k, L, and t_0). It is important to understand that when a three-parameter curve is fitted to a set of first-stage B.O.D. data, the values of k and L obtained may vary considerably from the k and L values obtained by a two-parameter fit to the same data. To illustrate, Figure 3 shows the two different curves fitted by both moment methods. The values of k and L for the three-parameter curve in this case deviate from those for the two-parameter curve. The three-parameter curve appears to be the more exact representation of the data in the range of the first seven days.

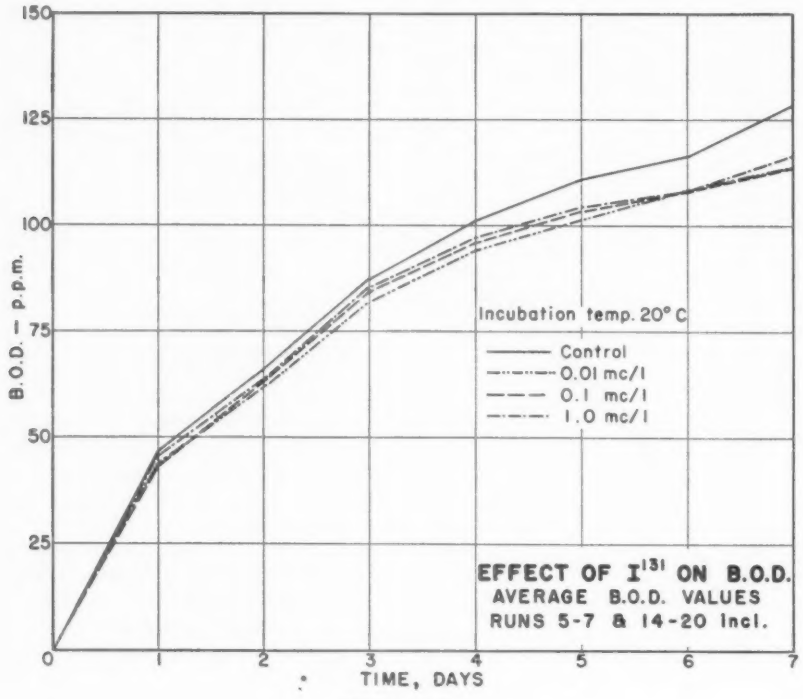

FIGURE 6.

It shows that the parameters are not necessarily equal in value. Since an initial lag or an apparent initial demand is not considered in the two-parameter formulation, it led to the development of the three-parameter method.

The data were analyzed by both moment methods. Because of some extreme variations in k and L values obtained by the three moment method and because such values differ markedly from the two-parameter values widely reported by other investigators, the statistical comparisons reported herein were based upon the values obtained by the two moment method. Even though the three-parameter fit is more sensitive to variations in the data, statistical studies of the "three moment" parameters did not alter any of the conclusions.

Results

Since a complete tabulation of all B.O.D. values is available (28), only the average B.O.D. values obtained for the first seven days at the various levels of P^{32} and I^{131} are shown in Figures 4, 5, and 6. Each figure presents data obtained only from runs comparing the same concentrations. Therefore, the curves are comparable with each other. No attempt was made to fit average curves to the plotted points, since each run may have a different lag and would make the validity of such procedure dubious. The points were simply connected by straight lines to show comparative trends. All values of the parameters reported were computed individually for each run and later averaged to obtain $\bar{k}$ and $\bar{L}$ for purposes of statistical analysis.

First-Stage Studies with P^{32}

The average B.O.D. values obtained from plain sewage as compared to sewage samples with initial concentrations of 0.1 and 1.0 mc. per liter of P^{32} are shown by Figure 4 to be in close agreement. There appears to be a slight lowering of the rate of biochemical oxidation at the 10.0-mc. per liter activity level. These observations are in agreement with the conclusions based on statistical analyses presented earlier (17); that is, P^{32} concentrations below 10.0 mc. per liter exert no significant effect on the first-stage parameters. The lowered reaction rate constant at 10.0 mc. per liter is of borderline significance (5 per cent level) and will be further analyzed. Studies by other investigators (25)(26) with higher levels of P^{32} demonstrated distinct retarding effects on *E. coli*.

Nitrification was measured simultaneously with B.O.D. determinations. Results of the average nitrite- and nitrate-nitrogen concentrations at the end of the seventh day of incubation are:

Determination	Control	P^{32} Added (mc./l.)		
		0.1	1.0	10.0
NO_2–N (p.p.m.)	0.023	0.024	0.024	0.004
NO_3–N (p.p.m.)	0.015	0.015	0.014	0.008

There is no difference in the amount of nitrites and nitrates formed up to and including the 1.0-mc. per liter concentration of P^{32}, whereas at 10 mc. per liter they are sharply decreased. This effect is similar to that on k values as previously noted.

Second-Stage Studies with P^{32}

There were altogether nine laboratory runs made for periods longer than seven days. The first five represented a continuation of the first-stage study up to 20 days and the last four extended to 30 days.

The average onset of rapid oxygen utilization occurred on the eleventh day for the control, 0.1-mc., and 1.0-mc. per liter samples. This onset was found to be delayed until the fifteenth day with 10.0-mc. samples. The computed values of reaction velocity constant and ultimate second-stage B.O.D. are as follows:

Av. Second-Stage Parameter[1]	Control	P^{32} Added (mc./l.)		
		0.1	1.0	10.0
$\bar{k}$	0.078	0.104	0.108	0.056
$\bar{L}$ (p.p.m.)	239	201	190	197

[1] The L values do not include oxygen uptake until the sixth day, because the values of k and L were computed from B.O.D. observations after reaerating the sewage on the fifth day.

These results point towards a reduction of the rate constant of oxidation in the presence of 10.0 mc. per liter of P^{32}, whereas a slight increase of k values in smaller concentrations is noted. A typical kind of behavior of biological systems in the presence of toxic materials is that small amounts of the toxicant stimulate the reaction until a certain threshhold concentration is passed, at which time the opposite effect may result. A similar toxic effect might be exerted by P^{32}. Such a trend was suggested for first-stage k values (27). A general reduction in the ultimate second-stage B.O.D. value is noted. However, the data are too meager for statistical analysis and these are generalized conclusions.

The data on nitrification during the second-stage oxidation are extremely variable, but do indicate the increased nitrification as the reaction proceeded. On the average, the 0.1- and 1.0-mc. samples produced slightly more nitrites and nitrates than the control and the 10.0-mc. samples.

First-Stage Studies with I^{131}

Average first-stage B.O.D. values in the presence of I^{131} were found to be consistently lower than those for the

TABLE I.—Reaction Velocity Constants, k, with Various Levels of Radioactivity (as I^{131})

Run	Value of k				
	Control	Initial Radioactivity (mc./l.)			
		0.01	0.1	1.0	10.0
1	0.129	——	——	0.254	——
2	0.142	——	——	0.151	——
3	0.143	——	0.185	——	——
4	0.134	——	——	0.168	——
5	0.116	0.146	0.150	0.160	——
6	0.215	0.247	0.240	0.241	——
7	0.227	0.236	0.224	0.239	——
8	0.206	——	0.214	0.205	0.230
9	0.198	——	0.201	0.189	0.193
10	0.207	——	0.176	0.192	0.173
11	0.160	——	0.221	0.227	0.243
12	0.128	——	0.130	0.147	0.130
13	0.173	0.170	0.173	0.157	——
14	0.149	0.179	0.177	0.181	——
15	0.104	0.113	0.124	0.117	——
16	0.158	0.165	0.160	0.162	——
17	0.087	0.118	0.137	0.146	——
18	0.154	0.150	0.155	0.155	——
19	0.185	0.147	0.152	0.179	——
20	0.199	——	——	——	0.197[1]

[1] A concentration of 0.001 mc. per liter I^{131} was used for this run.

TABLE II.—Ultimate First-Stage B.O.D., L, with Various Levels of Radioactivity (as I^{131})

Run	Value of L (p.p.m.)				
	Control	Initial Radioactivity (mc./l.)			
		0.01	0.1	1.0	10.0
1	132.7	——	——	91.0	——
2	116.8	——	——	119.5	——
3	124.4	——	124.0	——	——
4	108.5	——	——	102.7	——
5	154.5	129.6	122.5	129.1	——
6	213.0	180.1	195.3	195.5	——
7	214.3	204.0	209.2	203.3	——
8	200.2	——	192.9	195.7	185.3
9	188.6	——	168.0	175.0	170.8
10	168.2	——	153.4	155.6	158.2
11	258.3	——	210.6	208.0	194.7
12	188.5	——	177.1	166.0	176.2
13	161.8	164.6	160.9	176.4	——
14	211.4	174.0	181.0	180.3	——
15	126.1	117.0	117.4	114.5	——
16	171.7	145.2	148.3	146.6	——
17	139.7	98.4	94.3	93.3	——
18	138.1	187.5	134.3	136.0	——
19	81.5	77.7	76.5	69.8	——
20	120.8	——	——	——	153.4[1]

[1] A concentration of 0.001 mc. per liter I^{131} was used for this run.

control, as illustrated in Figures 5 and 6. Initial concentrations of I^{131} from 0.01 to 10.0 mc. per liter decreased the 5-day B.O.D. by 7 per cent and the 7-day B.O.D. by 10 per cent on the average as compared to the control. Apparently the least deviation resulted from an addition of 1.0 mc. per liter of I^{131}.

The parameters k and L computed in accordance with the two moment method from individual observations of 20 runs are presented in Tables I and II. In Table I, k values for the plain sewage are contrasted to those with 0.01, 0.1, 1.0, and 10.0 mc. per liter of I^{131}. Fewer experiments were conducted at the 10.0-mc. level of activity with I^{131} than with P^{32}. The reasons were: a) the high cost of 500 mc. of radioiodine required for each run, and b) because the biological concentrations shown to occur with P^{32} in streams have not been demonstrated for I^{131}.

Table II shows the ultimate first-stage B.O.D., as computed for the control and the radioactive sewage sam-

Determination	Control	I^{131} Added (mc./l.)			
		0.01	0.1	1.0	10.0
Runs 7 and 14–20 incl:					
NO_2-N (p.p.m.)	0.793	0.104	0.104	0.132	——
NO_3-N (p.p.m.)	0.035	0.021	0.020	0.027	——
Runs 9–13 incl:					
NO_2-N (p.p.m.)	0.540	——	0.138	0.134	0.212
NO_3-N (p.p.m.)	0.055	——	0.020	0.021	0.032

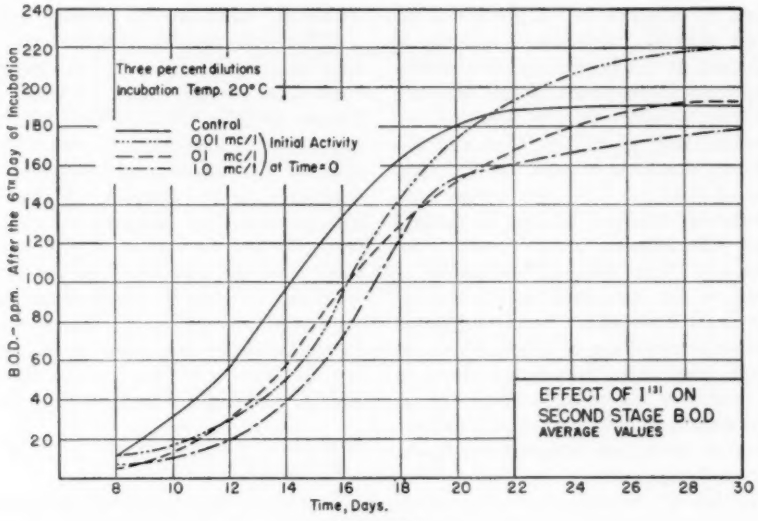

FIGURE 7.

ples. The tabulation portrays a reduction in the *L* values at the various concentrations of I^{131}.

After seven days of incubation, the nitrogen concentrations were as shown in the table at the bottom of page 890. This tabulation shows that both nitrite and nitrate formation were distinctly depressed in the presence of the concentrations of I^{131} under study.

Second-Stage Studies with I^{131}

Second-stage runs carried out to 30 days with initial concentrations of 0.01 to 1.0 mc. of I^{131} demonstrate a delayed onset of rapid oxygen utilization, as

TABLE III.—Progress of Nitrification in Five Second-Stage Runs; Average Values[1] of NO_2-N and NO_3-N with Various Concentrations of I^{131}

I^{131} (mc./L.)	Day											
	6	8	9	10	12	14	16	19	22	26	30	35
(*a*) Nitrite Nitrogen												
Control	0.04	0.05	0.11	0.14	0.11	0.44	0.69	0.40	0.04	0.01	0.01	0.02[2]
0.01	0.02	0.11	0.03	0.05	0.10	0.38	0.47	1.13	0.92	0.70	0.01	0.02[2]
0.1	0.02	0.03	0.03	0.04	0.11	0.48	0.78	0.86	0.27	0.24	0.01	0.01[2]
1.0	0.03	0.06	0.05	0.07	0.12	0.33	0.37	0.73	0.58	0.05	0.01	0.05[2]
(*b*) Nitrate Nitrogen												
Control	0.07[3]	0.09	0.08	0.16	0.23	0.19	0.14	0.22	0.51	0.38	0.35	0.80[2]
0.01	0.03[3]	0.05	0.02	0.03	0.02	0.03	0.05	0.24	0.23	0.26	0.60	0.87[2]
0.1	0.03[3]	0.05	0.05	0.03	0.03	0.03	0.03	0.17	0.29	0.28	0.49	0.62[2]
1.0	0.03[3]	0.02	0.02	0.03	0.03	0.05	0.09	0.18	0.40	0.45	0.47	0.82[2]

[1] P.p.m. in a 3 per cent sewage dilution.
[2] Averages from only 2 runs available.
[3] Averages from only 4 runs available.

shown in Figure 7. Although a reduced rate of biochemical activity is indicated at the beginning of nitrification, after approximately the fifteenth day the velocity of the reaction accelerates and surpasses that for the ordinary domestic sewage. In the presence of 0.01 mc. I^{131}, the lowest concentration studied, these deviations from the control were most pronounced. The rate of oxidation is shown to be stimulated after the initial lag. This effect again indicates possible stimulation of the biochemical system, similar to that encountered in the presence of minute amounts of toxic materials, as pointed out before. However, these are observations based only on four runs.

Studies of nitrification (28) show considerable variations in the amounts of nitrites and nitrates produced. Table III presents the average values.

The nitrite values with 0.01 mc. per liter of I^{131} are higher, on the average, than those for the control, 0.1-mc., and 1.0-mc. samples, which differ little from each other. The nitrates are slightly reduced for all concentrations of I^{131} compared to the control. These conditions manifest themselves particularly during the onset of the second stage and the exhibited trends either level off or reverse themselves after approximately 22 days. These effects of initial delay and later acceleration are in line with the effects on the B.O.D. values previously discussed.

Bacterial Densities in the Presence of P^{32} and I^{131}

Results of some typical bacterial density studies, carried out simultaneously on the samples used in these investiga-

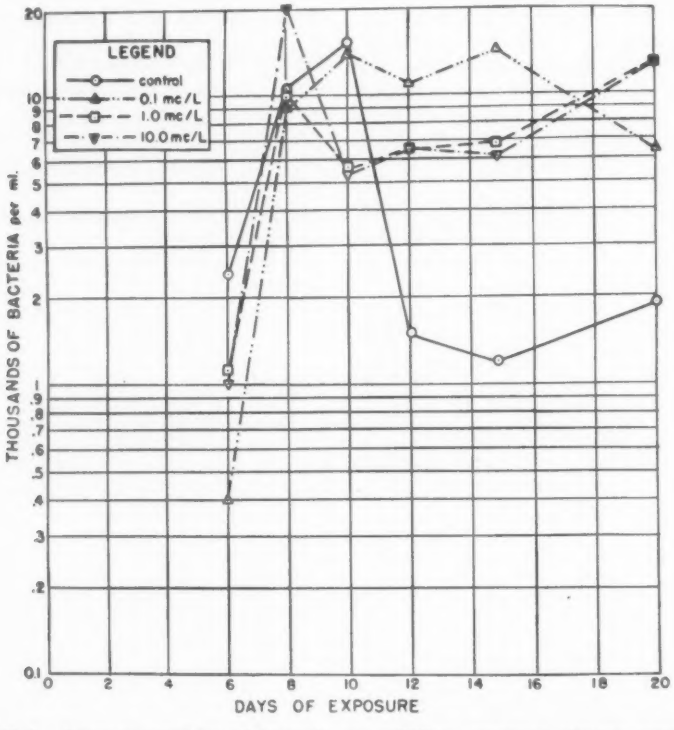

FIGURE 8.—Average numbers of bacteria per milliliter, tryptone glucose extract agar, incubation at 20° C., 48 hr., 4 per cent dilution; runs 40–43, inclusive, using P^{32}.

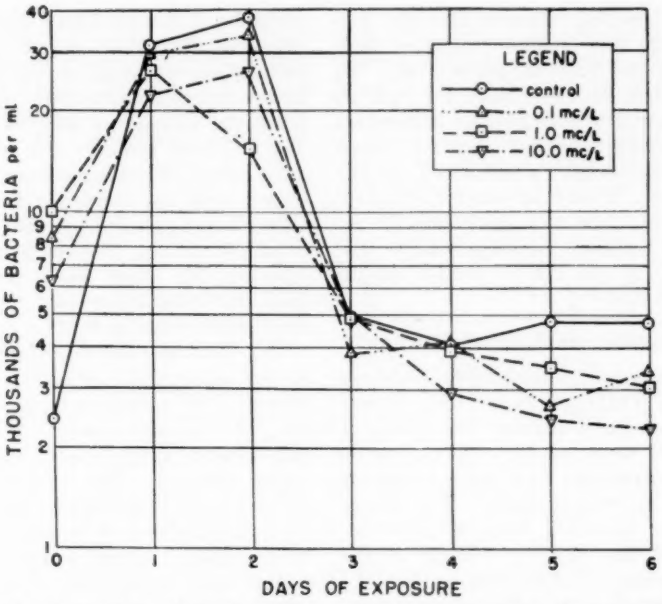

FIGURE 9.—Average numbers of bacteria per milliliter, tryptone glucose extract agar, incubation at 20° C., 48 hr., 4 per cent dilution; runs 10–13, inclusive, using I^{131}.

tions, are illustrated in Figures 8 and 9. The data are expressed as thousands of bacteria per ml. as diluted for the B.O.D. test. To convert to a raw sewage basis, it is necessary to multiply each value by the dilution factor, which is generally 25. The observations indicate that neither P^{32} nor I^{131} exerted any appreciable effects on bacterial growth.

Results of Counting Radioactive Solutions

During the progress of these investigations the relative activities of the various radioactive solutions were measured. The principal purpose was to determine whether or not the radioactive materials were being removed from the sewage dilutions by adsorption and sedimentation during the incubation period. To accomplish this, daily determinations were made of the activity of a distilled-water dilution of the isotope solution received from Oak Ridge. Similar determinations were made on samples taken from B.O.D. bottles, which were allowed to stand undisturbed. From the data thus obtained, the values of the decay constant, λ, in

$$N/N_0 = 10^{-\lambda t} \quad \ldots\ldots\ldots (3)$$

were computed by the method of least squares. In this equation, N_0 is the initial activity, and N is the activity at the end of t days. If any appreciable removal of the radioactive elements had occurred from the sewage dilution, this fact would have been brought out by an apparent increased value of the decay constant.

The computed values of λ showed that on the average there could not have been any appreciable separation of the radioactive isotopes from the liquid. With a generally accepted value of $\lambda = 0.02105$ for P^{32}, the average λ values for the isotope dilution, the 0.1-, 1.0-, and 10.0-mc. per liter sewage dilutions were 0.02623, 0.02179, 0.02177, and 0.03310, respectively. With a generally accepted value of $\lambda = 0.03763$ for I^{131}, the average values

for the isotope dilution and the 1.0-mc. per liter sewage dilution were 0.03764 and 0.04193, respectively. In comparing 32 runs with P^{32} and 20 runs with I^{131} added, these differences in the decay constant were not found to be significant as measured by the "t" test. It may be safely concluded, therefore, that the radioactivity remained rather homogeneously distributed in the B.O.D. bottles during these studies.

Statistical Analysis of Results

As expected, considerable variation between B.O.D. values resulted. It was important to determine how much of the total variation was due to experimental error and how much is real or caused by radioactivity. The larger variation occurred between runs because of the variable strength of the raw sewage. Values obtained on the same sewage with different concentrations of radioactivity exhibited smaller variations.

The data and parameters were then analyzed to determine the statistical significance of any differences between the values for the control and the radioactive samples. The statistical tests used were the Student "t" test and the "analysis of variance." Student's "t" distribution considers a variable which involves the sample standard deviation rather than the population standard deviation. This makes the test particularly applicable when the number of samples is small. The "t" test, however, can be applied only where two phenomena are compared, such as observed differences in a parameter at different concentrations of radioactivity. The analysis of variance on the other hand, provides a basis for comparing any number of phenomena with each other simultaneously. This method, like the "t" test, is also independent of population estimates. The analysis of variance and the "F variance ratio" utilize the grand mean by including all the data under analysis. The confidence with which results may thus be interpreted from an analysis of variance is relatively great. These statistical techniques may be applied with validity only to samples drawn from a normally distributed population. The data were tested for normality and no real deviation from a normal distribution was found.

In applying the "t" test, the variable in each instance was the difference between the "hot" and "cold" sewage parameter. The average differences between parameters were considered significant when they could be ex-

TABLE IV.—Average Differences* and the Probability, *P*, of Their Occurrences by Chance Alone for 5-Day B.O.D., 7-Day B.O.D., *k*, and *L* Values at Various Concentrations of I^{131}

Radio-activity** (mc./l.)	No. of Runs	5-Day B.O.D.		7-Day B.O.D.		Two Moment *k*		Two Moment *L*	
		$\bar{d}$†	P (%)	$\bar{d}$†	P (%)	$\bar{d}$§	P (%)	$\bar{d}$‡	P (%)
0.01 *vs.* control	10	−10.21	0.90	−14.98	0.20	+0.0097	20.5	−13.3	15.0
0.1 *vs.* control	16	− 7.44	0.16	−11.44	0.26	+0.0131	6.8	−17.2	0.03
1.0 *vs.* control	18	− 7.41	0.02	−11.71	0.04	+0.0221	1.7	−17.5	0.04
10.0 *vs.* control	5	− 9.72	1.92	−16.46	0.03	+0.0140	51.5	−23.7	8.0
0.01 *vs.* 1.0	10	+ 3.20	13.8	+ 2.84	23.5	+0.0066	17.5	− 3.42	57.0
1.0 *vs.* 10.0	5	− 0.66	59.0	− 2.40	34.5	+0.0018	85.5	− 3.20	50.0
0.1 *vs.* 10.0	5	+ 0.49	96.0	− 3.16	18.5	+0.0054	40.5	− 3.36	42.5

* $\bar{d}$ = hot − cold.

** Initial I^{131} radioactivity applied, in mc. per liter.

† $\bar{d} = \frac{\Sigma (y_h - y_c)}{n}$.

§ $\bar{d} = \frac{\Sigma (k_h - k_c)}{n}$.

‡ $\bar{d} = \frac{\Sigma (L_h - L_c)}{n}$.

pected to occur due to chance factors alone less than 5 per cent of the time.

The results of the "t" test applied to the 5-day and 7-day B.O.D. values and the "two moment" k and L values for I^{131} are shown in Table IV.

Discussion of Results

It is noted in Table IV that the differences observed in Figures 5 and 6 between average B.O.D. values are highly significant. In each case $\bar{d}$, the average difference for the 5-day and the 7-day B.O.D. values, is negative. With resulting probabilities, P, of only 0.02 to 1.92 per cent that these differences can occur due to chance factors alone, there is little doubt that the "radioactive" B.O.D. values are significantly lower than those for the control. Although the average k values with all concentrations of I^{131} showed an increase over those of the control, the L values were decreased. These differences are statistically significant only with the 0.1- and 1.0-mc. concentration. The relatively high probabilities obtained with the other two concentrations of I^{131} may have been caused by the greater variability due to the smaller sample. The entire results leave little doubt that the presence of I^{131} affects the biochemical oxidation considerably.

It appears that the ultimate first-stage B.O.D. is reduced, but the average reaction velocity constant is increased. An examination of the t_0-values, as computed by the "three moment method" (27), revealed a significantly prolonged lag period ($P = 0.5$ to 7 per cent) for all radioactive samples, amounting to 0.35 day on the average. This greater lag phase, the increased k-value, and the reduced ultimate first-stage B.O.D. are again characteristic of possible toxic effects due to the radioactivity.

The results of the statistical tests shown in Table IV further indicate that there is no real difference between effects caused by the various concentrations, although the range in concentration is a thousand-fold.

The results of the analysis of variance applied to several parameters of the reactions with P^{32} are as follows:

Results of Analyses of Variance (P^{32}) (Runs 17–39)

Parameter	Control	Conc. of P^{32} (mc./l.)			F-Ratio	P (%)
		0.1	1.0	10.0		
7-day B.O.D.	120	119	119	115	1.27	29.3
Two Mom. k	0.172	0.174	0.168	0.157	3.58	2.7
Two Mom. L	129	128	128	131	0.46	33.2

The analysis shows that the variation between calculated k-values at the various levels should occur on the average only 2.7 per cent of the time due to chance. The general conclusions reached by the results of statistical analysis of k-values is that it is quite improbable that the divergence noted between the control and the 10.0-mc. per liter concentration in Figure 2 could be solely due to chance. The actual difference, in p.p.m. of 7-day B.O.D.

$$\left[\bar{d} = \frac{\Sigma(y_h - y_c)}{n} = -4.6 \text{ p.p.m.} \right.$$

$$\left. \text{from 23 runs, } P = 13 \text{ per cent} \right],$$

is so small that it has little practical significance, although the evidence indicates that it is real and would be maintained under continued experiments.

Conclusions

Based on the investigations reported herein, the following conclusions for the first-stage of oxidation may be drawn:

1. Presence of P^{32} in an initial concentration of 10 mc. per liter appears to reduce the rate constant of oxygen utilization. The amount of reduction has little practical significance on the rate of B.O.D. in streams. It may become important in biological sewage treatment if this high level of radiophosphorus should be present.

2. Formation of nitrite- and nitrate-nitrogen is sharply decreased in the presence of 10 mc. per liter of P^{32}.

3. Presence of I^{131} in initial concentrations varying from 0.01 to 10 mc. per liter definitely reduces B.O.D. values and the ultimate first-stage B.O.D. parameter. Average reductions of 5-day B.O.D. are 7 per cent, for the 7-day B.O.D. 10 per cent, and for the ultimate B.O.D. about 11 per cent. In contrast, the reaction velocity constant is increased by about 10 per cent. These effects may be indicative of a toxic influence. There is little difference between effects produced within the thousand-fold range of concentration studied.

4. The formation of nitrite and nitrate is definitely decreased in the presence of all concentrations of I^{131}, especially the nitrite values.

During the second stage of biochemical oxidation, with fewer experiments the more generalized effects noted are:

1. Presence of 10 mc. per liter of P^{32} produced a 4-day delay in the onset of rapid oxygen utilization. The beginning of the second stage is characterized by a sharp rise in B.O.D. values, occurring on approximately the eleventh day with the control, 0.1-, and 1.0-mc. samples, whereas the 10-mc. per liter samples delay this rise until about the 15th day.

2. Average values of the reaction velocity constant, or $\bar{k}$, are decreased with 10 mc. per liter of P^{32} and increased with the lower concentrations of P^{32} present, exhibiting possible toxic effects on the reaction. Average values of the second-stage demand, or $\bar{L}$ (as computed after the sixth day of incubation), are reduced from about 240 p.p.m. to about 195 p.p.m., or by approximately 20 per cent, in the presence of all P^{32} concentrations studied.

3. Presence of I^{131} shows a delay in the onset of the expected increased utilization rate with all concentrations as compared to the control. This delay in initiating the second stage is most pronounced with the 0.01-mc. concentration of I^{131}. Later acceleration of the reaction rate is noted, particularly for the initially most retarded concentration.

4. Nitrites are increased with 0.01 mc. per liter of I^{131} compared with the higher concentrations and the control, which differ little from each other. Thus, the same stimulating effect on the lowest concentration is found once more. The nitrates were slightly reduced for all concentrations of I^{131} compared to the plain sewage.

Whereas these studies reveal effects on biochemical oxidation which generally are not large in magnitude, a cautious appraisal of possible effects on biological treatment methods such as activated sludge with extremely high rates of biochemical oxidation is justified. The delayed onset of active nitrification may be of sufficient import in stream pollution to warrant further study.

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ACTIVATED SLUDGE STUDIES

IV. Sludge Age and Its Effect on the Activated Sludge Process *

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Since well-aerated sludge in a fresh condition has always been considered essential for the efficient operation of activated sludge plants, it was considered desirable to study the effect of activated sludge that remained unaerated for various periods of time on the purification of sewage. A number of tests were made using activated sludge varying in age from 15 min. to 15 days. Settled sewage was treated, using fill-and-draw and continuous-flow operation.

Preliminary Studies

The preliminary studies consisted of collecting fresh sludge from the effluent end of one of the activated sludge aeration tanks at the Back River sewage treatment works serving Baltimore, Md., allowing it to remain unaerated, and determining the oxidation-reduction potential, the oxygen absorption, and the total bacterial count of the sludge after various time intervals. The oxidation-reduction potentials were measured by a Beckman pH meter. The oxygen absorption was determined at 20° C. at the end of 24 hr. by a Warburg apparatus, and total bacterial counts were made at 37° C. using trypticase soy agar medium. All determinations were made in triplicate.

Several samples of activated sludge were tested. Of the results obtained, those shown in Figure 1 are typical. The sludge was permitted to age from 1 to 96 hr. During this time the E_h potential decreased rather uniformly from 433 to 252 millivolts and was zero when the sludge was about 26 hr. old.

The 24-hr. oxygen absorption increased from 8.82 ml. per gram of activated sludge solids for sludge 1 hr. old to 10.66 ml. for sludge 6 hr. old. As the sludge increased in age after 6 hr., there was, in general, a decrease in oxygen absorption. With sludge 96 hr. old the 24-hr. oxygen absorption was 7.54 ml. per gram of solids. These results indicate that the biological activity of the sludge increased as the age of the sludge increased up to 6 hr.; as the age increased still further the biological activity decreased. Even with a negative oxidation-reduction potential at the end of 96 hr. there were sufficient aerobic bacteria to result in a 24-hr. oxygen absorption of 7.54 ml. per gram of dry solids.

The oxygen absorption curves of the sludges, the ages of which were 1, 4, 6 and 96 hr., are shown in Figure 2. Oxygen absorption was most rapid in the sludge that was 6 hr. old. Sludge of this age still had a high E_h potential of 335 millivolts and a high total bacterial count of 17,500,000 organisms per ml. One possible reason for the oxygen absorption increasing with the age of the sludge up to the 6-hr. period was that the aerobic bacteria may have passed through a lag phase and were most active at the end of the lag phase period.

The total bacteria count at 37° C. in unaerated sludge (Figure 1) increased rapidly from 2,200,000 per ml. to 23,000,000 within 1 hr. This rapid increase was most likely due to the bac-

* Part III of this series was published in This Journal, **23**, 8, 982 (Aug., 1951).

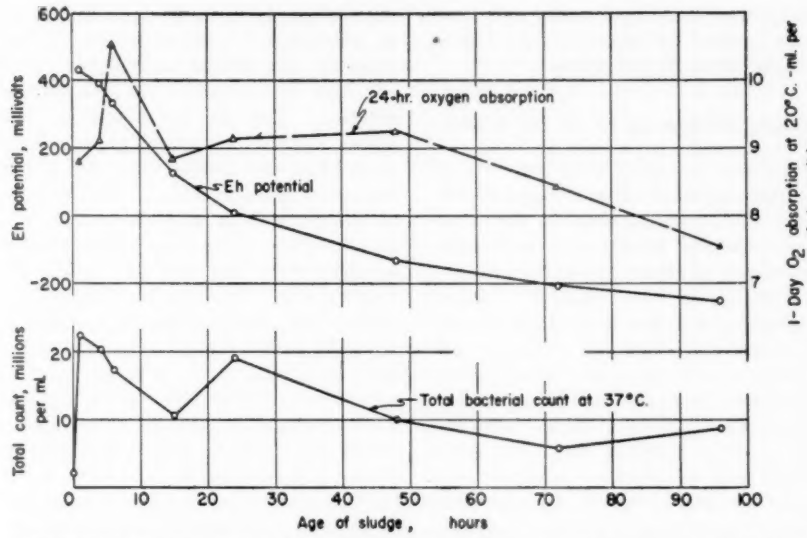

FIGURE 1.—Effect of activated sludge age on its E_A potential, oxygen absorption, and total bacterial count.

teria being in an excellent growth promoting medium. The count, which remained at high values in sludge up to 24 hr. old, varied from 10,000,000 to 21,000,000 per ml. As the sludge increased in age up to 96 hr., the total count decreased, ranging from 5,900,000 to 8,800,000 per ml. This de-

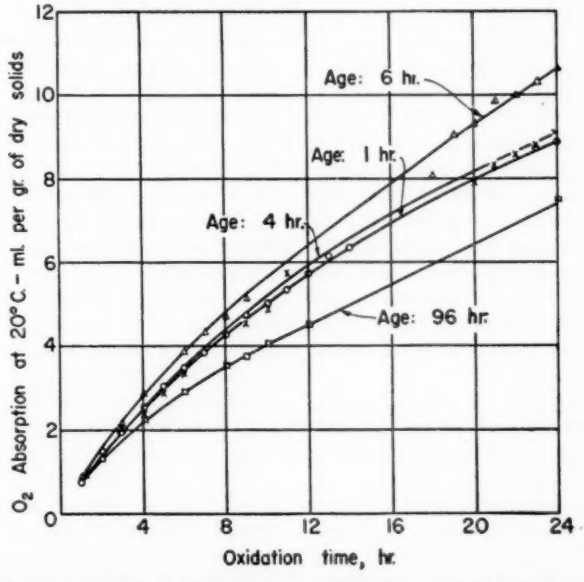

FIGURE 2.—Oxygen absorption of activated sludge of various ages.

crease was associated with and most likely caused by anaerobic conditions with negative E_h potentials.

Using Sludge up to 15 Days Old

The next group of tests consisted of determining what effect the age of activated sludge would have on the treatment of settled sewage. A representative sample of effluent from the primary settling tanks was collected, mixed thoroughly, and put into 12 containers. Approximately 3 gal. was added to each container. At the same time, sludge was drawn from the settling tanks following the activated sludge aeration tanks. This material was thoroughly mixed, and a sufficient quantity was added to each of the 12 containers so that the ratio by volume of settled sewage to sludge was about 3 to 1. The mixtures were aerated for 5 hr. Immediately thereafter the sludge was permitted to settle quiescently for the following periods of time:

Container No.	Settling Time (hr.)
1 and 1A (duplicate)	¼
2 and 2A (duplicate)	1
3 and 3A (duplicate)	4
4 and 4A (duplicate)	12
5 and 5A (duplicate)	24
6 and 6A (duplicate)	48

The supernatant then was siphoned off, and primary settled effluent was added at once. The ratio of sludge to sewage was such that the suspended solids in the mixtures varied from 1,000 to 1,176 p.p.m. The content of each container was aerated for 5 hr. and settled for 2 hr. A series of analyses (Table I and Figure 3) was made in conjunction with these tests.

The E_h potentials of the mixed liquors following the preliminary aeration period and immediately preceding the aging of the sludge were quite uniform, varying from 460 to 464 millivolts. Up to an aging period of 4 hr., the E_h potential of the sludge decreased only from 458 to 426 millivolts. However, the sludge that was 48 hr. old had an E_h potential of -56 millivolts. After aerating the sewage and sludge for 5 hr., the E_h potential in general increased. The E_h potentials of the mixed liquors, containing sludge from ¼ to 12 hr. old, ranged from 436 to 449 millivolts after aeration. In the case of the sludges 24 and 48 hr. old, the E_h potentials of the mixed liquors after aeration were 384 and 377 millivolts, respectively. The dissolved oxygen in each of the mixtures was high, ranging from 6.7 to 8.0 p.p.m. The sludge index after the 5-hr. aeration period varied from 372 to 523. These indexes were materially higher than those, which varied from 174 to 280, of the sludge collected at the same time from the main treatment works. The effect of the different ages of the sludges is reflected in the B.O.D. of the aerated and settled sewage and in the removal of B.O.D. The 5-day B.O.D. of the sewage after treatment was 1.5 p.p.m. when ¼-hr. old sludge was used, and 12.9 p.p.m. with 48-hr. old sludge. The removal of suspended solids was also less when the older sludges were used.

A similar group of tests was conducted with sludges that had aged from 1 hr. to 15 days (Table I and Figure 4). There was considerable difference in the E_h potentials of sludges 1 and 12 hr. old. The E_h potential of the former was 424 millivolts, and of the latter 94 millivolts. Sludge 15 days old had an E_h potential of -71 millivolts. When settled sewage was added to these sludges and they were aerated for 5 hr., there was a marked recovery in the E_h potential of the mixed liquor. Even in the case of 15-day-old sludge the E_h potential of the mixed liquor after aeration was 391 millivolts, only 38 millivolts less than that of the mixed liquor containing sludge 1 hr. old.

The sludge index was not materially affected by the age of the sludge. The sludge indexes of the mixed liquors containing sludge ranging in age from 1 to 24 hr. varied from 315 to 325;

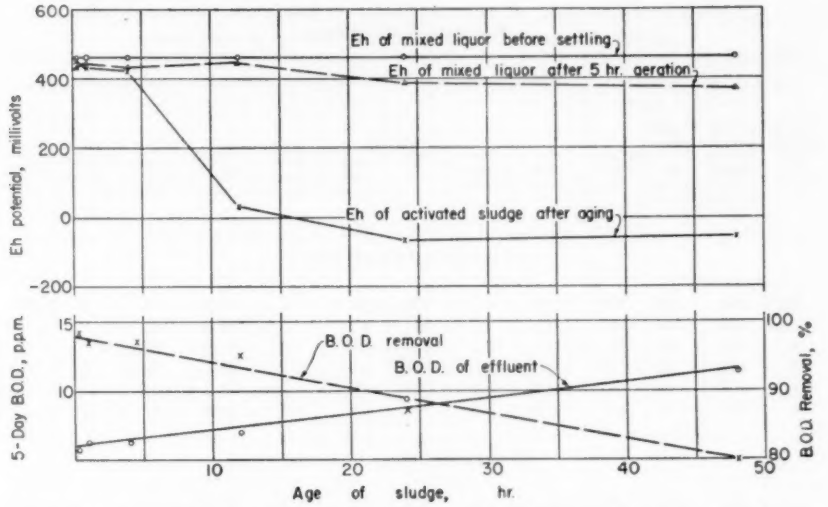

FIGURE 3.—Effect of activated sludge age on B.O.D. removals and E_A potentials.

using sludges 2 to 4 days old resulted in indexes ranging from 438 to 539. However, sludges that were 7 to 15 days old produced sludges with indexes from 234 to 310.

There was a gradual and rather uniform reduction in the B.O.D. and suspended solids removals as the age of the activated sludge increased. The B.O.D. and suspended solids removals were 96.8 and 92.5 per cent, respectively, when using sludge 1 hr. old, and 53.8 and 57.0 per cent, respectively, when using sludge 15 days old.

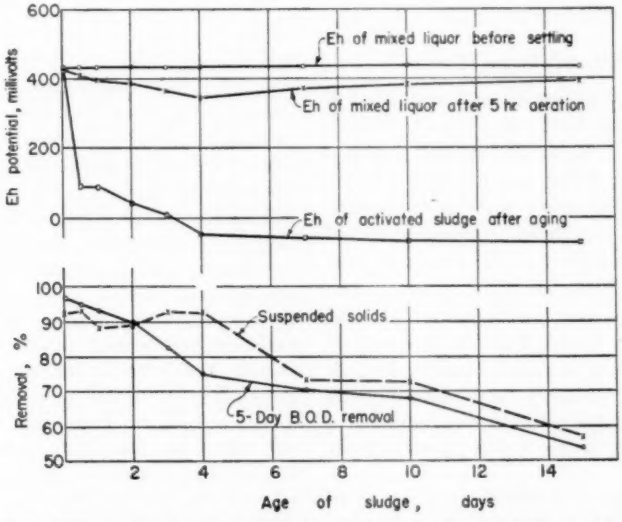

FIGURE 4.—Effect of activated sludge 1 to 15 days old on B.O.D. and suspended solids removals.

TABLE I.—Effect of Age of Activated Sludge on B.O.D. and Suspended Solids Removals from Sewage

Age of Sludge (hr.)	E_h Potential			Mixed Liquor		Sludge Index[2]	5-Day B.O.D. of Sewage			Susp. Solids in Sewage		
	Mixed Liquor Prior to Aging of Sludge[1] (mv.)	Sludge at End of Aging Period (mv.)	Mixed Liquor[2] (mv.)	Susp. Solids (p.p.m.)	Diss. Oxygen[2] (p.p.m.)		Before Treatment (p.p.m.)	After Treatment (p.p.m.)	Removal (%)	Before Treatment (p.p.m.)	After Treatment (p.p.m.)	Removal (%)
(*a*) First Series of Tests[3]												
0.25	464	458	438	1,094	6.7	372	81	1.5	98.1	81	0	100
1	463	434	442	1,026	6.7	434	81	2.5	96.9	81	0	100
4	460	426	436	1,026	7.2	502	81	2.5	96.9	92	1	98.9
12	462	32	449	1,032	7.8	523	81	4.0	95.1	80	0	100
24	461	−68	384	1,010	8.0	500	68	8.9	86.9	104	14	86.6
48	463	−56	377	1,046	7.8	449	64	12.9	79.8	87	12	86.2
(*b*) Second Series of Tests												
1	439	424	429	1,084	8.6	323	76	2.5	96.7	107	8	92.5
12	439	94	413	1,000	8.4	325	72	3.4	95.3	111	7	93.7
24	438	94	399	1,016	7.4	315	84	5.4	93.6	84	10	88.1
48	439	44	389	988	7.0	438	72	7.2	90.0	69	8	88.4
72	439	12	365	1,084	7.4	438	72	12.6	82.5	86	6	93.0
96	438	−45	345	984	8.0	539	72	18.0	75.0	68	5	92.6
168	439	−56	372	840	8.6	310	79.6	23.7	70.2	90	24	73.3
240	440	−64	385	728	8.2	234	72	23	68.0	72	20	72.2
360	439	−71	391	624	8.0	297	76	35.1	53.8	114	49	57.0

[1] Immediately following aeration.

[2] After 5-hr. aeration.

[3] Analyses in first series of tests are averages of duplicate determinations. Each E_h potential is average of three determinations.

Fill-and-Draw Tests

The next group of tests consisted of using sludge that was 1, 6, 12, 18, and 24 hr. old. Each sludge was put into a separate 3-gal. container, to which was added primary settling tank effluent. The resulting concentration of suspended solids in the mixtures varied from 1,012 to 1,202 p.p.m. The sewage was then aerated for 4 hr. and settled for 2 hr. The clarified supernatant was siphoned off and analyzed, additional primary tank effluent was added, and the process was repeated a number of times on a fill-and-draw basis.

The analytical results are given in Table II. Throughout the test the suspended solids in the mixed liquors were maintained between 820 and 1,202 p.p.m., and the dissolved oxygen varied from 7.0 to 8.4 p.p.m. As was to be expected, the E_h potential of the sludge varied inversely with its age; the E_h potential of sludge 1 hr. old was 327 millivolts and of sludge 24 hr. old 66 millivolts. However, the E_h potential recovered quite rapidly when the sludge was mixed with sewage and aerated for 4 hr. For example, the E_h potential of mixed liquor that contained sludge 24 hr. old was 385 millivolts after the first 4-hr. aeration cycle.

The age of the sludge had no apparent effect on the sludge index. The index during five cycles of operation when using sludge that was 1 hr. old varied from 122 to 142, whereas with sludge that was 24 hr. old the index

TABLE II.—B.O.D. and Suspended Solids Removals in Sewage by Activated Sludge 1 to 24 Hr. Old after Repeated Cycles of Aeration and Settling

Treatment Cycle No.	E_h Potential[1]			Mixed Liquor		Sludge Index[2]	5-Day B.O.D. of Sewage			Susp. Solids in Sewage		
	Mixed Liquor Prior to Aging of Sludge (mv.)	Sludge after Aging Period (mv.)	Mixed Liquor[2] (mv.)	Susp. Solids (p.p.m.)	Diss. Oxygen[2] (p.p.m.)		Before Treatment (p.p.m.)	After Treatment (p.p.m.)	Removal (%)	Before Treatment (p.p.m.)	After Treatment (p.p.m.)	Removal (%)
					(*a*) 1-Hr. Old Sludge							
1	427	327	402	1,184	7.0	122	68.4	28.0	59.1	66	39	40.9
2		286	405	1,056	7.6	137	68.4	17.0	75.2	76	33	56.6
3		338	411	1,016	7.2	138	68.4	15.8	77.1	77	49	36.4
4		287	399	1,012	8.0	138	68.4	10.3	85.1	72	26	63.8
5		288	378	1,056	8.0	142	68.4	9.0	86.6	81	19	76.6
					(*b*) 6-Hr. Old Sludge							
1	427	203	391	1,202	7.2	112	56.4	21.5	61.9	80	36	55.0
2		236	407	1,056	7.2	128	56.4	18.7	66.8	88	49	44.3
3		277	389	1,068	8.2	127	56.4	13.0	77.0	83	28	66.3
4		269	373	1,004	8.0	130	52.4	8.2	84.4	84	21	75.0
					(*c*) 12-Hr. Old Sludge							
1	428	194	405	1,012	7.0	129	52.4	28.5	45.7	71	59	16.9
2		195	394	1,048	8.4	125	52.4	16.8	68.0	80	34	57.5
3		233	378	996	8.0	126	52.4	10.2	80.7	77	32	58.4
4		277	393	896	7.6	145	64.4	13.4	79.2	51	14	72.6
5		307	402	820	7.4	159	64.4	13.4	79.2	55	24	56.4
6		274	399	1,032	7.4	146	64.4	8.2	87.4	59	5	91.6
					(*d*) 18-Hr. Old Sludge							
1	427	105	393	1,052	8.0	124	52.4	42.3	19.3	86	62	27.9
2		282	382	1,076	8.0	112	64.4	20.0	68.9	60	24	60.0
3		268	386	1,028	7.6	117	64.4	15.6	75.8	57	29	49.2
4		246	388	1,154	7.8	108	64.4	13.4	79.3	52	24	53.9
5		244	386	900	8.0	117	56.4	10.5	81.4	47	17	63.8
6		256	395	852	8.0	123	64.4	10.3	84.2	60	13	78.3
7		266	398	892	7.2	129	56.4	13.7	75.9	43	8	81.5
8		282	382	884	7.4	130	56.4	9.1	84.0	64	14	78.2
9		278	380	864	7.6	139	56.4	8.2	85.6	52	16	69.3
					(*e*) 24-Hr. Old Sludge							
1	429	66	385	1,076	7.1	107	60.4	53.5	11.4	83	57	31.4
2		259	387	1,036	7.4	116	56.4	25.8	54.3	43	29	32.6
3		248	399	1,016	8.0	138	56.4	14.4	74.6	46	32	30.6
4		219	383	960	8.0	135	56.4	10.7	79.7	58	27	53.4
5		218	390	956	7.8	120	56.4	14.5	74.4	70	17	75.7
6		248	395	960	7.4	120	56.4	8.5	85.0	66	15	77.3
7		300	387	1,028	7.2	117	56.4	7.5	86.8	62	12	80.7
8		251	384	960	7.0	120	56.4	8.9	84.3	64	12	81.3

[1] Each E_h potential is the average of three determinations.
[2] After 4-hr. aeration.

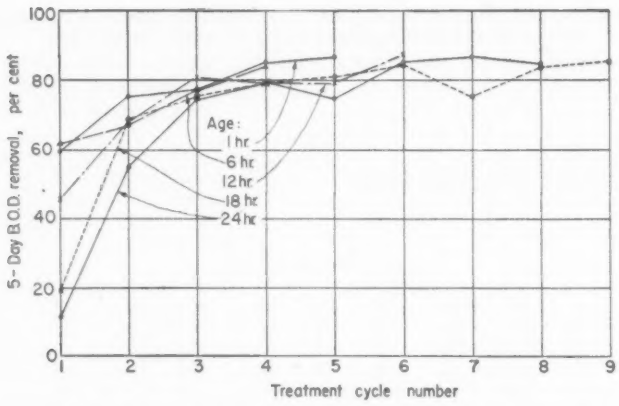

FIGURE 5.—B.O.D. removal using activated sludge of different ages.

varied from 107 to 138 during eight operating cycles.

As indicated in Table II and Figure 5, 5-day B.O.D. removals were quite low during the first cycle of operation in the case of the older sludges. By the end of the fourth treatment cycle, however, removals were approximately 80 per cent or better, irrespective of the age of the sludge.

The removal of suspended solids from the sewage was also affected by the sludge age. After four or five treatment cycles removals increased in general to 65 to 70 per cent or better.

Continuous-Flow Tests

The next group of tests was made using a small, continuous-flow, activated sludge pilot plant. The aeration tank was 16 ft. by 5 ft. in plan, with a working depth of 2 ft. 9 in. The mixed liquor was aerated by a paddle-wheel, which was partially submerged in the mixed liquor adjacent to one of the longitudinal tank walls. The final settling tank was 6 ft. in diameter, 7 ft. deep, and was provided with a hopper bottom. Primary settling tank effluent was treated at the rate of 5.5 g.p.m. The theoretical detention period of the aeration tank was 5 hr.; that of the final settling tank, 2 hr. The plant was operated for several days to get it functioning uniformly. During the last 48 hr. of operation prior to shutting down the plant, the suspended solids in the aeration tank averaged 801 p.p.m. Routine analyses made during this 48-hr. period (Table III and Figure 6) served as a basis for comparison. The operating results were quite good: the sludge index averaged 89, and the 5-day B.O.D. and suspended solids removals were 90.6 and 88.5 per cent, respectively. At the end of the 48-hr. period the aerator was shut down for 24 hr., and the flow to the plant was discontinued. During this period the E_h potential of the supernatant in the aeration tank decreased from 447 to 349 millivolts, and the E_h potential of the sludge in the final settling tank decreased from 248 to 97 millivolts.

At the end of the 24-hr. shutdown period aeration was resumed and sewage was treated at the rate of 5.5 g.p.m. for 4 days. The suspended solids and the dissolved oxygen in the mixed liquor were maintained between 820 to 1,118 p.p.m. and 5.7 to 7.5 p.p.m., respectively. Samples of the untreated sewage, the mixed liquor, the sludge, and the effluent were collected hourly and either analyzed at once or composited every 8 hr., depending upon the analysis being made. Sludge sam-

TABLE III.—B.O.D. and Suspended Solids Removals in Sewage by Activated Sludge 24 and 48 Hours Old by Continuous Aeration

Treatment Period (hr.)	E_h Potential (mv.)		Mixed Liquor		Sludge Index	5-Day B.O.D. of Sewage			Susp. Solids in Sewage		
	Mixed Liquor	Settled Sludge	Susp. Solids (p.p.m.)	Diss. Oxygen (p.p.m.)		Infl. (p.p.m.)	Effl. (p.p.m.)	Removal (%)	Infl. (p.p.m.)	Effl. (p.p.m.)	Removal (%)
(*a*) 48-Hr. Preliminary Aeration Period											
48	439	370	801	6.2	89	124.4	11.7	90.6	139	16	88.5
(*b*) 24-Hr. Shutdown Period											
—	447[1,2]	248[2]	—	—	—	—	—	—	—	—	—
—	349[1,3]	97[3]	—	—	—	—	—	—	—	—	—
(*c*) Aeration Period Following Shutdown Period											
8	349	198	956	6.1	74	128.4	26.6	79.3	178	17	90.5
8	389	280	1,098	5.8	96	144.4	17.2	88.1	189	9	95.3
8	421	288	826	7.0	130	84.4	13.0	84.7	130	6	95.4
8	419	299	1,068	6.6	95	124.4	13.9	88.8	151	7	95.4
8	429	339	1,080	7.2	93	128.4	12.6	90.2	217	3	98.6
8	429	349	900	6.2	136	72.4	12.4	82.9	146	5	96.6
8	429	354	820	7.5	80	100.0	5.9	94.1	111	17	84.6
8	442	386	942	7.2	73	120.0	13.4	88.8	159	14	91.2
8	438	359	1,118	7.5	94	88.0	11.1	87.4	140	15	89.3
8	437	375	1,118	7.3	94	104.4	6.1	94.0	94	5	94.7
8	440	374	1,026	6.4	93	144.4	8.1	94.4	139	6	95.6
8	440	374	1,066	5.7	85	136.4	7.9	94.2	108	8	92.6
(*d*) 48-Hr. Shutdown Period											
—	441[1,2]	248[2]	—	—	—	—	—	—	—	—	—
—	184[1,3]	1[3]	—	—	—	—	—	—	—	—	—
(*e*) Aeration Period Following Shutdown Period											
8	339	178	836	7.3	63	152.0	40.1	73.6	245	43	82.5
8	379	248	644	6.8	51	156.0	41.9	73.3	184	66	64.2
8	399	253	662	6.9	69	96.0	25.2	73.7	103	24	76.7
8	400	262	630	8.1	72	108.0	18.7	82.7	192	25	86.9
8	410	294	1,038	8.0	55	120.0	20.0	83.3	216	24	88.8
8	411	307	734	8.1	72	68.0	11.1	83.6	127	18	85.8
8	413	309	876	7.5	77	144.0	21.7	85.1	240	17	92.9
8	421	333	1,038	7.3	77	144.0	20.7	85.7	137	14	89.8
8	424	346	1,366	7.3	82	96.0	14.0	85.4	172	25	85.5
8	426	349	1,414	8.0	85	124.0	12.0	90.3	142	6	95.7
8	435	359	1,066	8.0	99	112.0	11.9	89.4	131	2	98.4
8	433	362	1,814	7.0	85	80.0	7.5	90.6	82	5	93.9
8	437	358	1,598	7.7	91	104.0	7.8	92.5	223	13	94.2
8	440	366	1,828	7.4	85	120.0	9.0	92.5	226	15	93.4
8	440	370	1,917	7.5	81	96.0	7.3	92.4	182	13	92.9
8	440	370	1,092	8.1	89	144.0	8.7	94.0	186	8	95.6
8	440	373	1,726	7.5	79	180.0	10.5	94.2	192	9	95.3
8	440	374	756	7.8	80	120.0	6.4	94.7	140	8	94.3
8	440	374	1,024	7.7	79	144.0	7.1	95.0	139	10	92.8
8	440	374	1,008	6.5	80	192.0	10.2	94.7	144	12	91.7
8	440	374	838	8.5	81	132.0	6.7	94.9	129	10	92.3

[1] Sewage supernatant. [2] At beginning of shutdown period. [3] At end of shutdown period.

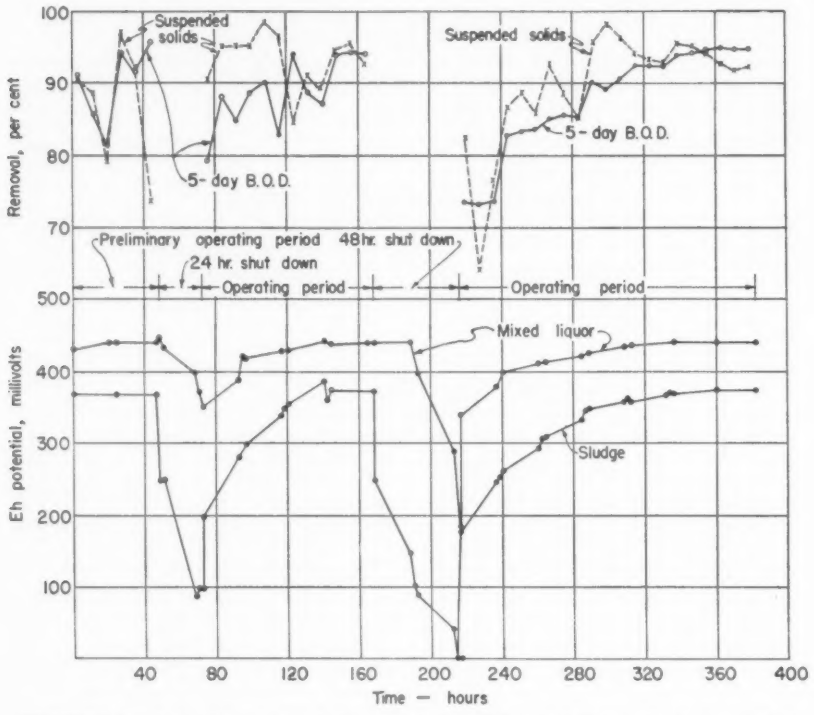

FIGURE 6.—Operating results before and after 24-hr. and 48-hr. shutdown periods.

ples were obtained from mixed liquor that had settled for 30 min. The recovery of the E_h potential of the mixed liquor was quite rapid, requiring approximately one day to attain a value of 421 millivolts. The rise in the potential of the sludge was somewhat slower. Values of more than 350 millivolts were reached during the third day of aeration. The sludge index was affected little if any by the 24-hr. shutdown period; with two exceptions the sludge index was less than 100. The 5-day B.O.D. dropped to 79.3 per cent during the first 8 hr. of operation after the shutdown period. After that the removals varied from 82.9 to 94.4 per cent. The removal of suspended solids was not adversely affected by the shutdown, but in fact was higher.

After 4 days of operation, the plant was shut down for 48 hr. The E_h potential of the supernatant sewage in the tanks dropped from 441 to 184 millivolts, and the E_h potential of the settled sludge dropped from 248 to 1 millivolt. At the end of the 48-hr. shutdown period operation was resumed. It took 5 days for the E_h potential of the sewage to reach 440 millivolts, the value it had prior to the shutdown period, and 6 days for the potential of the sludge to reach 374 millivolts. B.O.D. and suspended solid removals of 90 per cent or better were obtained on the fourth day of operation. The sludge index, which varied from 51 to 99, was apparently unaffected by the 48-hr. shutdown.

The next series of tests consisted in determining what effect discontinuing aeration for 96 hr. would have on the activated sludge process. The pilot plant was operated for several days

TABLE IV.—B.O.D. and Suspended Solids Removals in Sewage by Activated Sludge 96 Hours Old by Continuous Aeration

Treatment Period (hr.)	E_h Potential (mv.)		Mixed Liquor		Sludge Index	5-Day B.O.D. of Sewage			Susp. Solids in Sewage		
	Mixed Liquor	Settled Sludge	Susp. Solids (p.p.m.)	Diss. Oxygen (p.p.m.)		Infl. (p.p.m.)	Effl. (p.p.m.)	Removal (%)	Infl. (p.p.m.)	Effl. (p.p.m.)	Removal (%)
(*a*) 48-Hr. Preliminary Aeration Period											
48	448	376	1,062	7.4	175	146.2	7.1	95.2	117	2	98.3
(*b*) 96-Hr. Shutdown Period											
—	448[1,2]	249[2]	—	—	—	—	—	—	—	—	—
—	134[1,3]	−27[3]	—	—	—	—	—	—	—	—	—
(*c*) Aeration Period Following Shutdown Period											
8	300	144	1,158	7.7	126	156.4	56.8	63.6	174	47	73.0
8	350	230	944	6.7	130	148.4	53.3	64.0	160	31	80.7
8	370	250	1,116	8.0	119	136.4	49.5	63.6	110	17	84.5
8	391	258	1,072	6.8	87	180.0	51.3	71.4	179	21	88.3
8	400	280	888	6.3	102	172.0	49.2	71.4	149	20	86.6
8	416	299	786	7.9	86	144.0	40.0	72.2	122	16	86.8
8	420	305	700	7.0	82	152.0	38.0	75.0	191	23	87.9
8	430	325	826	6.2	95	188.0	42.7	77.4	176	21	88.1
8	430	329	926	7.1	92	116.0	27.6	76.2	115	26	77.4
8	432	335	938	7.0	81	176.0	36.2	79.4	198	31	84.3
8	436	341	1,050	6.4	93	96.0	40.9	79.3	150	25	83.3
8	438	345	976	6.6	105	152.0	32.3	78.7	140	37	73.6
8	438	347	1,012	6.3	92	132.0	22.8	82.8	211	36	82.8
8	442	350	764	5.8	105	184.0	27.6	85.1	192	30	84.3
8	442	352	670	7.5	112	120.0	21.6	82.0	123	23	81.3
8	443	355	918	6.9	95	144.0	21.6	85.1	175	27	84.6
8	446	357	672	5.2	112	148.0	21.0	85.8	156	22	85.8
8	446	357	570	7.1	82	120.0	15.5	87.1	116	17	85.3
8	447	360	600	5.5	96	104.0	11.1	89.2	140	18	87.3
8	449	363	674	5.6	119	116.0	11.7	89.9	149	19	87.3
8	449	365	652	7.5	132	96.0	10.3	89.3	138	18	87.0
8	449	367	640	6.6	113	120.0	10.1	91.6	211	25	88.1
8	450	370	792	5.8	160	132.0	9.3	92.8	180	22	87.8
8	450	373	886	6.7	161	100.0	7.6	92.4	115	15	86.9
8	450	375	660	6.5	125	120.0	6.3	94.7	143	20	86.0
8	450	375	472	5.7	281	152.0	8.3	94.4	161	23	85.7
8	450	375	806	6.8	169	108.0	6.6	93.9	119	18	84.8
8	450	375	760	6.6	158	112.0	5.9	94.7	135	13	90.3
8	450	375	670	5.7	172	140.0	6.0	95.7	160	16	90.0
8	450	375	570	7.0	170	104.0	4.9	95.2	129	13	90.0
8	451	375	626	6.7	138	136.0	6.1	95.5	151	11	92.7
8	450	375	686	5.0	139	164.0	7.1	95.7	158	13	91.8
8	451	375	680	3.5	136	104.0	5.2	95.0	121	11	90.9

[1] Sewage supernatant. [2] At beginning of shutdown period. [3] At end of shutdown period.

until uniform operating conditions were attained. Operating results for the last 48 hr. prior to the 96-hr. shutdown period are given in Table IV. The E_h potentials of the mixed liquor and the settled activated sludge were 448 and 376 millivolts, respectively. The sludge index was 175, the 5-day B.O.D. removal was 95.2 per cent, and the suspended solids removal was 98.3

per cent. At the end of the 96-hr. shutdown period the E_h of the mixed liquor was 134 millivolts and the E_h of the activated sludge was − 27 millivolts. Aeration was then resumed and sewage was treated at its normal rate of flow. During the 11-day duration of the test, the suspended solids in the mixed liquor varied from 472 to 1,158 p.p.m. and the dissolved oxygen ranged from 3.5 to 8.0 p.p.m. On the seventh day of operation the E_h potential of the mixed liquor had reached 449 millivolts, and on the ninth day the E_h of the activated sludge reached 375 millivolts. These potentials were approximately the same as those of the mixed liquor and the sludge prior to the shutdown period. With one exception the sludge index was considerably less than the index before the shutdown period. For the first 8 hr. of operation after the shutdown the 5-day B.O.D. removal was 63.6 per cent. Within 5 days this removal was better than 80 per cent and within 10 days it was slightly greater than 95 per cent. After 10 days the removal of suspended solids was approximately 90 per cent.

Discussion and Conclusions

1. The age of activated sludge is indicated by its E_h potential. The E_h potential decreased quite rapidly during the early stage of its aging. The time that it took to reach an E_h potential of zero varied from about 15 hr. to 3 days. When the potential was less than zero, it decreased at a much slower rate.

2. Aged activated sludge with a low positive or a negative E_h potential when added to sewage and aerated 4 or 5 hr. produced a mixed liquor with a potential less than normal.

3. The total 37° C. bacteria count in activated sludge was greatest when the material was 1 hr. old. Sludges ranging in age from 48 to 96 hr. had a much lower count, presumably due to anaerobic conditions.

4. The 24-hr. oxygen absorption of the sludge was a maximum with material 6 hr. old and a minimum with material 96 hr. old.

5. There was no indication that the age of the activated sludge had any effect on the sludge index.

6. That many of the aerobic organisms in the activated sludge survived under anaerobic conditions is indicated by the fact that a 5-day B.O.D. removal of 53.8 per cent was obtained when activated sludge (Table I) 15 days old was used to oxidize settled sewage. Using sludge 2 days old (Table III) resulted in a 73.6 per cent B.O.D. removal, and using sludge 4 days old (Table IV) gave a 63.6 per cent removal.

7. Although B.O.D. removals were adversely affected by using aged activated sludge, it soon recovered its effectiveness in oxidizing sewage. As judged by the results obtained (Tables III and IV) when treating the sewage by the continuous-flow method, B.O.D. removals were back to normal in time periods approximately equal to $(2t + 2)$, where t equals the age of the sludge in days.

8. The experiments indicate that the best results are obtained when using fresh activated sludge. However, if aeration should be discontinued for a few hours, or even for a few days, an appreciable reduction in B.O.D. removal should result upon resuming aeration, and normal B.O.D. removals should be obtained after a protracted aeration period, the length of which would depend on the duration of the shutdown.

Acknowledgments

The Back River sewage treatment works, where the foregoing experiments were conducted, is under the general direction of P. L. Holland, director, Department of Public Works, and John J. Hunt, sewerage engineer. R. J. Trautman, principal associate engineer, has direct supervision of the sewage works, and Paul L. Smith is plant superintendent.

BACTERICIDAL EFFECTS OF SEWAGE CHLORINATION*

II. Theoretical Aspects

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A previous paper by the authors (1) describes statistical analyses of sewage treatment plant data for a relation between the M.P.N. and residual chlorine. Inasmuch as the statistical methods employed did not prove satisfactory when chlorine dosages were substituted for residuals, the need for a rigorous development of the effects of bactericidal agents was indicated rather than a continuation of empirical methods.

The theory offered in the following is not meant to be a definitive statement of chlorination effects. Rather it is intended to demonstrate the results that can be obtained when the implications of the basic assumptions are explored; to determine how well the theoretical results are in accord with laboratory and field examinations; and, in general, to indicate the avenues of approach to the problem of bactericidal chlorination that may prove most fruitful.

Theory

The death of bacteria under unfavorable environmental conditions has been formulated by Chick (2). The relationship of the number of bacteria surviving at any time to the time elapsed is expressed by Chick's law as:

$$\log B = \log B_0 - k\,t$$

in which

B = final number of bacteria;
B_0 = initial number of bacteria;
t = elapsed time; and
k = velocity constant.

This is a constant-rate process; the percentage of organisms killed per unit is constant. The absolute number killed per unit of time decreases with the passage of time, due to the decrease in the number of bacteria.

Other empirical relationships between the concentration of killing agents and the number of bacteria remaining have been offered by Fair and associates (5) and by Eliassen (3) (4), and a relationship between the time of exposure and the number of bacteria remaining has been formulated by Fair *et al.* (5).

The following theoretical development is based on the diffusion of toxic materials into bacterial cells. Assuming that the kill of bacteria by agents such as chlorine follows the diffusion of such agents into the cell, the concentration of diffusant within a given cell may be determined at any period of time after the introduction of the diffusable material in the bacterial environment. The analysis of a reversible diffusion process for a single bacterium is similar to that of Rashevsky (6).

Reversible Process

In accordance with the diffusion theory, the flow of diffusible material

* Presented at 25th Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; New York, N. Y.; October 6–9, 1952.

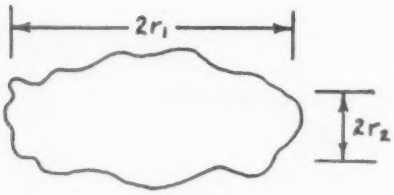

FIGURE 1.

through any cross-section under consideration is proportional to the concentration gradient. Likewise, the flow through a membrane is directly proportional to the difference in concentrations on opposite sides of the membrane. Therefore, the total flow through a membrane per unit of time is equal to the product of the concentration differential across the membrane, the area of the membrane, and a proportionality factor known as the permeability. For the cell of general dimensions $2r_1$ and $2r_2$ (Figure 1), the average flow per unit of time through the end walls is

$$q_e = f(r_2)\, h\, (C_0 - C_1) \ldots\ldots (1)$$

and through the side walls

$$q_s = f(r_1, r_2)\, h\, (C_0 - C_2) \ldots\ldots (2)$$

in which

h = coefficient of permeability;
C_0 = outside concentration of diffusant;
C_1 = average internal concentration of diffusant adjacent to the ends;
C_2 = average internal concentration of diffusant adjacent to the sides;
$(C_0 - C_1)$ = average concentration differential across end membrane;
$(C_0 - C_2)$ = average concentration differential across side membrane;
$f(r_2)$ = total area of the end membrane; and
$f(r_1, r_2)$ = total area of the side membrane.

Inside of the cell the transport of material is likewise actuated by diffusion processes, but instead of the flow through a membrane, as discussed previously, the flow is through the cell liquid. Flow by diffusion through a liquid is proportional to the concentration gradient, as contrasted to the concentration difference across a membrane. The average difference in concentration from the sides to the cell interior as a whole is $(C_2 - \bar{C})$, where $\bar{C}$ is the average internal concentration. The concentration at the center of the cell is less than that at the periphery, since the flow is into the cell. Hence, the average concentration occurs at some point between the cell center and the membrane. Then the average concentration gradient away from the sides is $\dfrac{C_2 - \bar{C}}{m_2 r_2}$, where m_2 is a dimensionless number less than unity. The total flow per unit of time is the product of the concentration gradient, the area, and a proportionality factor known as the coefficient of diffusion. The flow per unit time from the side walls into the cell is equal to

$$q'_s = D_i \left[\frac{C_2 - \bar{C}}{m_2 r_2} \right] f(r_1, r_2) \ldots (3)$$

where D_i is the coefficient of diffusion for the cell liquid and the specific diffusing material under consideration. For the end walls,

$$q'_e = D_i \left[\frac{C_1 - \bar{C}}{m_1 r_1} \right] f(r_2) \ldots\ldots (4)$$

If it is assumed that the cell wall does not consume any of the diffused material, the flow through the membrane is equal to the flow away from the membrane. On this basis Eqs. 1 and 4 are equal, as are Eqs. 2 and 3, as follows:

$$f(r_2)\, h\, (C_0 - C_1) = D_i \frac{(C_1 - \bar{C})}{m_1 r_1} f(r_2) \ldots (5)$$

$$f(r_1, r_2)\, h\, (C_0 - C_2) = D_i \frac{(C_2 - \bar{C})}{m_2 r_2} f(r_1, r_2) \ldots (6)$$

The total amount of substance within the cell is some function of its dimensions, $f_a(r_1, r_2)$ equal to the volume of the cell, multiplied by the average concentration $\bar{C}$. The time rate of change of this amount is equal to the sum of the amounts entering the side and end walls per unit of time or

$$f_a(r_1, r_2) \frac{d\bar{C}}{dt} = f(r_2)\, h\, (C_0 - C_1) + f(r_1, r_2)\, h\, (C_0 - C_2) \ldots (7)$$

Eqs. 5 and 6, after slight manipulation, yield the following relationships:

$$C_0 - C_1 = \frac{D_i\, (C_0 - \bar{C})}{D_i + h\, r_1\, m_1} \ldots (5a)$$

$$C_0 - C_2 = \frac{D_i\, (C_0 - \bar{C})}{D_i + h\, r_2\, m_2} \ldots (6a)$$

Substitution of these values in Eq. 7 gives

$$\frac{d\bar{C}}{dt} = (C_0 - \bar{C}) \times \left[\frac{h\, D_i}{f_a(r_1, r_2)} \left(\frac{f(r_2)}{D_i + h\, r_1\, m_1} + \frac{f(r_1, r_2)}{D_i + h\, r_2\, m_2} \right) \right] \ldots (8)$$

The expression in the brackets is a constant depending on the physical characteristics of the cell, its coefficient of cell wall permeability, internal diffusion coefficient, and its volume-area relationships. Substituting k for this expression, Eq. 8 becomes

$$\frac{d\bar{C}}{dt} = k\, (C_0 - \bar{C}) \ldots\ldots (9)$$

which is readily integrated to

$$\log\, (C_0 - \bar{C}) \Big|_{t=0}^{t=t} = -\, k\, t \Big|_0^t \ldots (10)$$

If at a time $t = 0$ the internal concentration, $\bar{C}$, is zero, then

$$\bar{C} = C_0 - C_0\, e^{-kt} \ldots\ldots (11)$$

The constant, k, may be termed a measure of susceptibility, since low values of k denote more hardy organisms in the sense that their internal concentrations tend to be relatively lower. In general, susceptible cells are small, and have high permeabilities and coefficients of diffusion.

Irreversible Process

If it is stipulated that the diffusible matter combines irreversibly with an enzyme or some other component involved in the cell's metabolism, as may be the case with chlorine, the effective concentration difference across the membrane is $(C_0 - 0)$. Also, if it be assumed that the outside concentration remains constant, this differential remains constant with respect to time. Then, as before, the total amount entering a cell per unit time is

$$q = h\, A\, C_0 \ldots\ldots (12)$$

where

A = area;
h = coefficient of permeability; and
C_0 = external concentration.

Although one cannot in this case speak of an internal concentration of diffusant, since it is assumed to be always zero, it is possible to substitute $\bar{C}_d$, or the average internal dosage. It is equal to the amount of matter that has diffused into the cell, expressed as a concentration, and is analagous to the average internal concentration, $\bar{C}$, used previously. The total internal dosage is equal to the average dosage, $\bar{C}_d$, times the volume $f(L)$. Its rate of change is equal to

$$f(L) \frac{d\bar{C}_d}{dt} \ldots\ldots (13)$$

As previously, this rate of change is equal to the total amount of material

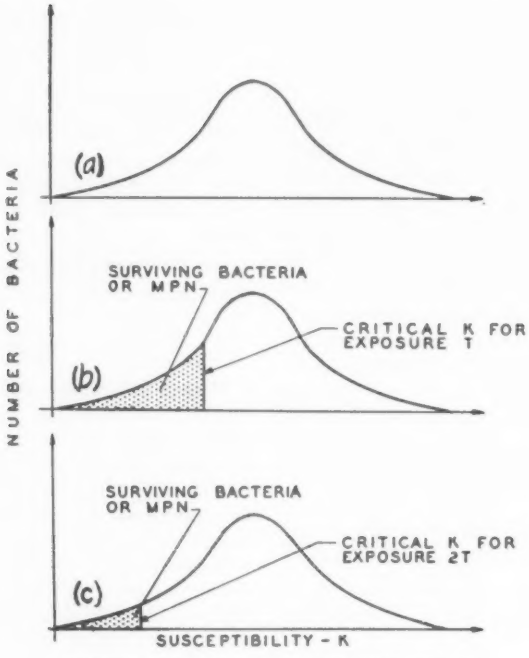

FIGURE 2.—Susceptibility distribution curve:

(a) For normal bacterial population.
(b) For critical k at exposure time t.
(c) For critical k at exposure time $2t$.

that enters the cell per unit time, or

$$f(L)\frac{d\bar{C}_d}{dt} = h\,A\,C_0 \quad \ldots\ldots (14)$$

Integrating, Eq. 14 becomes

$$\bar{C}_d\Big|_{t=0}^{t=t} = \frac{h\,A\,C_0\,t}{f(L)}\Big|_0^t \quad \ldots\ldots (15)$$

If at time $t = 0$, $\bar{C}_d = 0$, as may reasonably be assumed with chlorination, that is to say before chlorine is added to a bacterial suspension, there is no chlorine present internally in the cell, then

$$\bar{C}_d = \frac{h\,A\,C_0\,t}{f(L)} = \phi\,C_0\,t \ldots (15a)$$

Both indices of susceptibility that have been developed thus far, k and ϕ, contain terms for volumes, area, and permeability. These indices are consistent in that susceptible cells are characterized by comparatively small-sized cells and large permeabilities. They differ in that there is no recognition of the diffusion coefficient in the irreversible system, because the entering material immediately combines with cell material upon entering the cell and does not enter into an intracellular diffusion process.

An analysis of the data derived from either laboratory or field experiments makes it reasonable to assume a variability in bacterial populations. In their reactions to an agent such as chlorine, bacteria can vary in either of two major ways, as follows:

1. They may be different by virtue of their physical characteristics of size, permeability, and diffusion coefficient, which will cause a difference in the

internal concentrations or external dosages.

2. They may require varying internal concentrations or dosages to effect their death or inactivation.

If it can be assumed that only the first of these is variable, then the lethal internal dosage or concentration is constant and the number of bacteria surviving under specified conditions may be defined in the manner outlined as follows:

The bacteria are arranged with respect to their physical characteristics: for the reversible diffusion method the arrangement is made according to k values or susceptibilities, as shown in Figure 2.

The internal concentration, $\bar{C}$, of any group of bacteria with equal susceptibilities, k_i, may be determined by substitution in

$$\bar{C} = C_0 - C_0 e^{-k_i t} \quad \ldots\ldots (17)$$

for given conditions of time and external concentration, since C_0, k_i, and t are given, which is sufficient for determination of $\bar{C}$.

The internal concentrations of those bacteria with high k values will be higher than those with low k values, for a given time exposure. Some bacteria will have an internal concentration higher than the critical lethal concentration, if C_0 exceeds the lethal internal concentration, and some will have concentrations less than the critical. If the lethal internal concentration is specified, say as $\bar{C}_L$, the k value corresponding to the lethal concentration can be determined by solving Eq. 11 for k, which gives

$$k_t = \frac{1}{t} \log \left[\frac{C_0}{C_0 - \bar{C}_L} \right] \quad \ldots (18)$$

All bacteria with higher k values will have greater than the lethal internal concentration and are presumably killed, whereas those with lower values will remain alive. The number of surviving bacteria is equal to the sum of those bacteria with internal concentration less than lethal, equal to the area under the distribution curve of k to the left of the critical k, as shown in Figure 2b.

The critical k corresponding to an exposure time of, say, double that given previously, other factors remaining constant, will be equal to

$$k_{2t} = \frac{1}{2t} \log \left[\frac{C_0}{C_0 - \bar{C}_L} \right] \quad \ldots (18a)$$

or one-half of the previous value. The M.P.N. under these conditions is again equal to the area under the curve to the left of the critical susceptibility, as shown in Figure 2c. Therefore, if the distribution of susceptibility is stipulated and the lethal concentration is assumed, it is possible to describe precisely the interrelationship of external concentration, time of exposure, and the number of bacteria surviving. Curves of M.P.N. *versus* external concentration, and the three-dimensional plot of M.P.N. *versus* time and external concentration, may be plotted if it can be assumed that susceptibility is distributed normally (that is, that bacteria assume the shape of the familiar bell-shaped curve when arranged with respect to k.) The M.P.N. is then defined as

$$\text{M.P.N.} = \frac{N_0}{\sigma\sqrt{2\pi}} \int_{-\infty}^{k} e^{-(k-\bar{k})^2/2\sigma^2} dk$$

in which

N_0 = original number of bacteria;
k = average susceptibility; and
σ = variance of k, describing the "spread" of the distribution (that is, whether closely or loosely spread out about the mean).

Under these conditions the determination of M.P.N. is equivalent to the determination of

$$\int_0^x e^{-t^2} dt = x - \frac{x^3}{3 \cdot 1!} + \frac{x^5}{5 \cdot 2!} - \frac{x^7}{7 \cdot 3!} + \ldots (20)$$

which requires an infinite series in the equation for M.P.N. The manipulation of the equation describing the variation of M.P.N. with exposure time and external concentration is unwieldy. However, because tables of the area under the normal curve are available, it is possible to draw curves of the type previously discussed, although their equations are not simply formulated.

Figure 3 shows the plot of curves determined on the basis of a normal distribution of susceptibility, a reversible diffusion process, and a constancy of lethal concentration.

If instead of a reversible reaction an irreversible reaction is assumed, curves similar to those in Figure 4 may be plotted. For these curves a normal distribution of ϕ is assumed. The critical value of ϕ, determining which bacteria have a critical internal dosage, is given by

$$\phi_c = \frac{\bar{C}_d}{C_0 t}$$

in which

$\bar{C}_d$ = lethal internal dosage, assumed constant for all bacteria regardless of ϕ value;
C_0 = external concentration;
t = time of exposure; and
ϕ = critical "susceptibility."

The characteristics of the curves in Figure 4 are, in general, similar to those in Figure 3, with one major difference. When employing the reversible diffusion theory, no bacteria are killed at external concentrations less than the lethal internal concentration; but with the irreversible theory here employed some bacteria are killed even at very low concentrations.

Rather than vary the external concentration, the time exposure may be varied and the external concentration kept constant. According to the respective theories of an irreversible or reversible reaction, the critical ϕ or k,

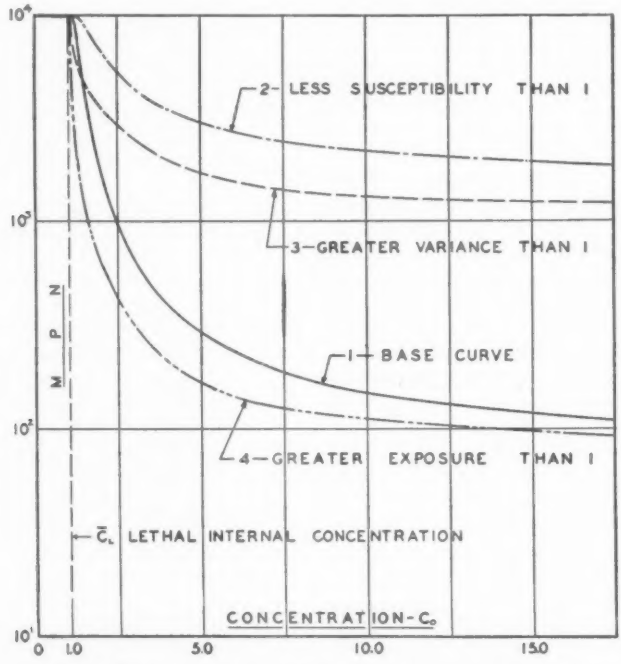

FIGURE 3.—Theoretical mortality curve; reversible process.

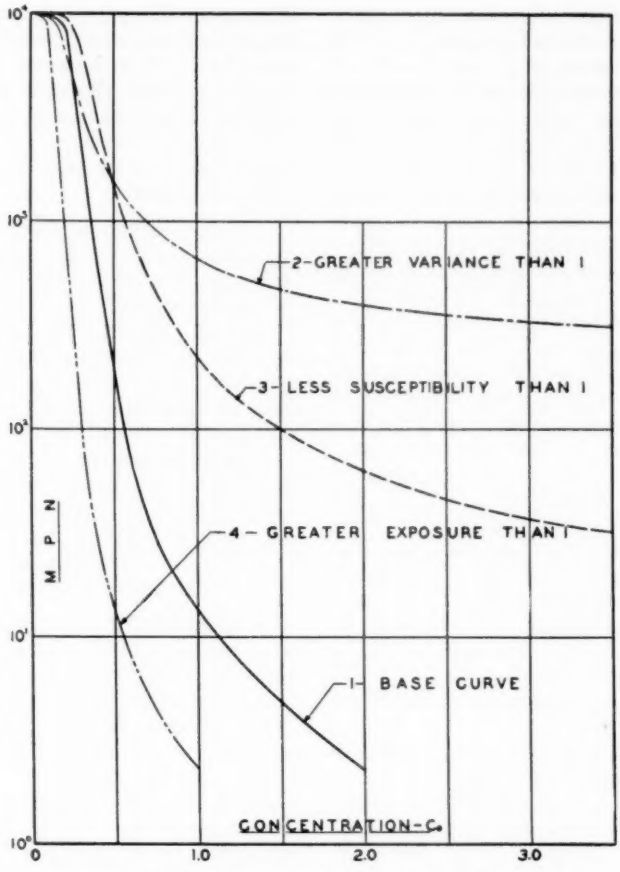

FIGURE 4.—Theoretical mortality curve; irreversible process.

as defined by

$$\phi = \bar{C}_d/C_0 t = \alpha/t \ldots\ldots (21)$$

$$k = \frac{1}{t} \log \left[\frac{C_0}{C_0 - \bar{C}} \right] = \beta/t \ldots (22)$$

is used as the separating point between live and dead bacteria. In Eqs. 21 and 22 $\bar{C}_d/C_0$ and $\log \left[\frac{C_0}{C_0 - \bar{C}} \right]$ are shown as equal to the parameters α and β, respectively, because for any given concentration they are constant. It is apparent that similar curves will be obtained on the basis of both an irreversible and a reversible reaction if the distribution of ϕ and k are similar; Eqs. 21 and 22 differ only in the parameters α and β.

Discussion

The usefulness of any theory depends to a large extent on its agreement with physical fact. If there is a close agreement of the results obtained in the field and laboratory with the results predicted by theory, then the usefulness of the theory is increased. The theory may be tested further by its use in the prediction of results under conditions unlike those in the laboratory, and the continued comparison of these predicted and actual results may be made.

If data have been obtained under more or less controlled conditions it is generally desirable to use these test results in the confirmation of theories, rather than field data, which are subject to the influence of uncontrolled and often unmeasured variables.

Operational plant data are subject to influences that are capable of masking the bactericidal efficiency of chlorination. Environmental conditions of pH, temperature, and the amount of food and mineral matter necessary for its life processes may affect the survival of *E. coli*. Hence, the observed mortalities of *E. coli* when subjected to chlorine concentrations may represent the net rate of killing due to the combination of the previously outlined effects and a toxic agent, rather than the rate of killing due to the toxic agent alone. It is necessary to separate the effect of these "natural" factors if the cause of death due to the addition of chlorine is to be evaluated. In view of this, the authors have deemed it advisable to first compare the results of the proposed theory with laboratory data.

Jordan and Jacobs (7) have obtained much controlled laboratory data concerning the death of *E. coli* when subjected to variations in phenol concentration, exposure time, pH, and temperature. Their results, pertaining to the effect of variations in the concentration of germicide and the time of exposure, may be summarized as follows:

1. The death rates varied widely in each of the experiments. At first, at either low concentrations or times of exposure, there was an increasing rate, which, after rising to a peak in many instances, began to decline.
2. The curves of percentage of bacteria remaining *versus* time are similar to those of percentage of bacteria remaining *versus* external concentration.

The theory offered by the authors gives curves that are in accordance with this general description, but the investigations reported herein indicate that a variation of lethal internal concentration, or lethal dosage, is required to obtain a higher degree of conformity with the data of Jordan and Jacobs.

In all of the theories outlined it was assumed that either of two conditions exists, as follows:

1. With a reversible reaction there is one lethal internal concentration that kills any one of the bacteria under consideration when this concentration is reached. Bacteria die under differing conditions of exposure and external concentration because of a variation in their physical characteristics controlling the diffusion of the lethal agent into the bacterium and not because of a variation in the internal concentration that is required to kill a bacterium.
2. With an irreversible process there is one internal dosage that kills any one of the bacteria under consideration.

Investigations by the authors to date have revealed that a mere random variation of the lethal internal dosage or concentration with susceptibility does not change the curves obtained to any extent other than to change one of the constants involved.

In order to agree more fully with the data of Jordan and Jacobs it appears that either there exists a relationship of physical susceptibility and the lethal internal concentration or dosage, or that the distribution of susceptibility is non-normal. If it is stipulated that more susceptible bacteria require lower lethal dosages or concentrations than their physically less susceptible counterparts, curves are obtained that fit the data more closely. This implies that the susceptibility of a bacterium should include not only its "susceptibility" as defined by its physical characteristics, which is the sense in which it has heretofore been used in this paper, but should also include the varying lethal dosage or concentration required to kill organisms.

One of the underlying assumptions used in the development of the theory

offered here is that a bacterium does not alter its physical characteristics controlling the diffusion of chlorine during the exposure to chlorination. It is entirely possible that the continued subjection of a bacterium to the presence of chlorine in its environment deteriorates the cell wall and allows an easier entrance of chlorine during the later stages of chlorination. At present, no attempt has been made to account for this physical change of bacteria. However, it is mentioned here as one of the possible modifications that may be required in the theory.

A major difficulty that lies in the path of checking the theory offered here is the measurement of the variables that affect the viability of bacteria. It is difficult to accurately assess the effective concentration of chlorine and the exposure time, as well as the number of bacteria surviving.

Summary and Conclusions

A general theory of bacteria kill, applicable to the disinfection of sewage has been developed. Although its ramifications have not as yet been fully explored and its validity not fully established, the theory to a large extent appears to agree with laboratory and field data.

The development of the technical skills necessary for a knowledge of the physico-chemical mechanisms involved in the kill of bacteria by lethal agents will make possible a more precise evaluation of the methods offered in this presentation. Some of the assumptions on which the methods have been based will probably be altered upon the attainment of these skills. But whether the alterations are of major or minor consequences, it is the hope of the authors that the method of approach offered to the complicated problem of sewage chlorination will be of value by having indicated some of the myriad influencing factors in this problem and by having outlined an attempt at a plausible solution.

Acknowledgments

Morris B. Smith, Meyer Deitch, Marshall E. Ferguson, Fred W. Gross, and Robert Pedersen, all staff members of the Interstate Sanitation Commission, assisted in the field analyses, aided in the required calculations, critically analyzed the subject matter of this paper, and provided the mental stimulation which materially aided this study.

The authors express their appreciation for the assistance afforded them in a series of special studies by the operating personnel of the sewage treatment plants in the villages of Lawrence, Roslyn, and Great Neck (Bayview Avenue plant), N. Y., and the responsible municipal, county, and state officials.

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DEOXYGENATION OF SEWAGE—A DISCUSSION *

By Richard L. Woodward

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Many of the authors' criticisms of the monomolecular equation as an expression for use in analysis of B.O.D. data are well taken. In recent years numerous studies of the B.O.D. reaction have shown clearly that the deoxygenation rate coefficient is variable and that biological oxidation is indeed a complex phenomenon. Studies of the persistence of various organic compounds in natural waters have shown that they disappear in strange and wonderful ways, with no regard for a monomolecular equation. The velocity coefficient, k, is a particularly unstable parameter, as can be shown from the fact that the relatively small errors inherent in the dissolved oxygen tests made to determine points on a B.O.D. curve will cause rather large variations in k values.

The authors' data show a not uncommon characteristic of B.O.D. data on sewages or other well-seeded organic wastes relatively free of toxic materials. The greatest departure of the observed values from the fitted monomolecular equation are in the early stages and these early observed values lie above the curve. Thomas (1) has found that a considerably better fit of much B.O.D. data can be obtained by using a second-order reaction formula:

$$\frac{dy}{dt} = k(L - y)^2 \quad \ldots\ldots (1)$$

$$k\,t = \frac{1}{L - y} - \frac{1}{L} \quad \ldots\ldots (2a)$$

or

$$y = \frac{k\,L^2\,t}{1 + k\,L\,t} \quad \ldots\ldots (2b)$$

The reaction velocity coefficient can be made independent of concentration by defining $k_b = k\,L$. Then

$$y = L\,\frac{(k_b\,t)}{(1 + k_b\,t)} \quad \ldots\ldots (3)$$

This can be linearized to the form $z = ax + b$ by letting

$$\frac{1}{y} = z, \quad \frac{1}{t} = x, \quad \frac{1}{k_b\,L} = a, \quad \text{and} \quad \frac{1}{L} = b.$$

The parameters k_b and L can be determined graphically by plotting the data and fitting a line, or analytically by the least squares method.

There is no theoretical reason why such a formulation is to be preferred to some other—say a third- or fourth-order or even some fractional-order reaction equation. This does not imply that the reactions involved in the B.O.D. test are bimolecular reactions any more than fitting a monomolecular reaction equation to other B.O.D. data implies that the reactions are in fact monomolecular. The second-order reaction equation fits the data well with the use of only two parameters and facilitates determination of the two parameters from the data.

Such a curve has been fitted to the authors' data shown in their Table I. These data are reproduced in Table I. The values obtained are $L = 164$ and $k_b = 0.33$. The fit is as good as that obtained with the authors' logarithmic equation. The logarithmic equation

$$y = S(0.85 \log a\,t + 0.41) \ldots (4)$$

fits the second-order reaction equation excellently over the range of values of $a\,t$ from 1 to 10. The parameters of the two different types of equations are

* The original paper was published in This Journal, **25**, 4, 419 (Apr., 1953) and **25**, 5, 566 (May, 1953).

so related that $L = 1.6S$ and $k_b = 0.35a$.

It is pertinent to consider the purpose, if any, of fitting an equation to B.O.D. data. The authors review the uses of the B.O.D. test in their opening paragraph. For most purposes the standard 5-day, 20° C., B.O.D. test is adequate. For such purposes one can forget about reaction rates and the course of the reaction. Virtually the only practical need for such information has been in connection with studies of oxygen depletion and recovery in streams or other bodies of water receiving oxygen-demanding wastes. Such studies are generally aimed at determining the ability of a stream to dispose of wastes without undue oxygen depletion.

For this purpose the oxygen sag formula of Streeter and Phelps (2), or one of the numerous modifications, elaborations, or simplifications of this basic formula, are commonly used. An equivalent approach developed earlier by Phelps (3) is sometimes used. In any case the principal unknown factor which is sought is the reaeration capacity of the stream. In the present state of the art it is not possible to determine this directly from measurable physical characteristics of the stream (although it is to be hoped that this will some day be possible). The simplest and probably the commonest solution is to assume a value. The only other way out is to derive the value from measurements of dissolved oxygen at various points along the stream, data on stream flows and velocities, and information on the amount of oxygen removed from the stream by oxygen-demanding materials in it.

TABLE I.—Comparison of Interpolated Observed B.O.D. with Computed B.O.D. Values by Logarithmic and Second-Order Reaction Formulas

Day	B.O.D. (p.p.m.)			Diff. from Obs. B.O.D. (%)	
	Obs.[1]	Log. Form. Calc.[1]	2nd-Order Form. Calc.	Log. Form.[1]	2nd-Order Form.
1	45	41.0	40.6	8.9	9.8
2	65.4	66.3	65.3	1.4	1.5
3	80	81.1	81.6	1.4	2.0
4	91.5	91.5	93.3	0	2.0
5	100	99.8	102	0.2	2.0
6	108.5	106.3	109	2.0	0.5
7	114	111.9	114	2.5	0
8	119	116.8	119	1.8	0
9	123	121.2	123	1.5	0
10	125	125.0	126	0	0.8
11	129	128.6	129	0.3	0
12	133	131.7	131	1.0	1.5
13	136	134.7	133	1.0	2.2
14	137	137.3	135	0.2	1.5
16	139	142.3	138	2.4	0.7
18	140	146.3	140	4.5	0
Mean (1–18 days)				1.8	1.5
Mean (2–18 days)				1.3	0.9

[1] From Table I, THIS JOURNAL, 25, 4, 427 (Apr., 1953).

This last information is obtained from B.O.D. tests and it is necessary to know the amount of ultimate first-stage B.O.D. removed in passage from station to station. In the absence of photosynthetic activity, sedimentation, scour, adsorption by bottom organisms, and inflow of additional water or wastes, the amount of B.O.D. removed is determined by subtracting the ultimate first-stage B.O.D. at the downstream station from that at the upstream station. Corrections must be made if the mentioned processes are active. From this, knowing the time of flow between stations, the deoxygenation rate in the stream can be determined. From these data, together with dissolved oxygen measurements at the two stations, the reaeration characteristics of the stream can be computed.

The difficulties and uncertainties attending this method of measuring reaeration are considerable but need not be discussed here. So long as such a method is the best one available some way is needed of determining how much oxygen demand has been satisfied at the expense of the dissolved oxygen resources of the stream. In this respect the monomolecular equation of

Phelps or the second-order equation suggested by Thomas (1) are preferable to the logarithmic formula proposed by the authors. It is not at all clear how one would proceed using the authors' formula to obtain the information needed, whereas with the equations which give a finite L value the information is obtained by a simple subtraction.

From this it is clear that the value of L is the principal result of practical significance that is needed from B.O.D. tests made in connection with water pollution studies. Whatever formula is used to fit the data should provide a value of L that is not affected by the time at which observations are started. For instance, the value of L determined from observations over the period 0 to 10 days should be the same as that determined using only the data from 1 to 10 days and adding the observed B.O.D. at 1 day. The values of the reaction velocity coefficient k need not be independent of the portion of the curve used, so long as no attempt is made to derive L values from a single observed B.O.D. test (for example, a 5-day B.O.D.).

The authors' conclusions to Part II of their paper say in part:

"1. The logarithmic equation has more biological significance and is better adapted to the interpretation of biological oxidation phenomena than the monomolecular equation."

Although it is not entirely clear what the term "biological significance" means in this context, it is difficult to understand how an equation which gives infinite negative values at zero time and which has no upper bound as time increases, can be considered as having much "biological significance." It must be considered as an empirical equation, as must any equation used for this purpose.

The authors also conclude:

"2. The parameters of the logarithmic equation are easier to compute."

Although this may be true for some of the older methods of analysis used, the time required to determine the parameters of the monomolecular equation using the moment method is probably less than that required by the graphical method proposed for determining the parameters of the logarithmic equation. The time required to fit the second-order reaction equation should be roughly the same as that required to fit the authors' equation to a series of B.O.D. results. In any case, the time and expense of such routine analysis is such a small fraction of the time and expense of obtaining the data as to be unimportant.

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Industrial Wastes

CHROMIUM WASTES—RECOVERY OR TREATMENT?*

I. Minimizing Waste by Process Control

By Kenneth S. Watson

Coordinator of Waste Treatment, General Electric Company, Schenectady, N. Y.

Modern industry is factoring sound waste control and treatment into the installation of all new facilities and into the modernization and renovation of existing operations. One of the segments of industry which must keep pace with this modern industrial wastes philosophy is the metal-finishing industry. Today there is much concern over one of the more important wastes from the metal-finishing industry, that of excessive chromium ions in waste waters.

In line with industry's continuing efforts to develop recovery methods in lieu of treatment for most types of wastes, such work has been underway for some time in the chromium waste field. In quite recent years, the use of ion exchange to permit chromium ions in waste waters to be removed and used back in the process has been practiced in a considerable number of plants. Since, therefore, chromium wastes represent a type that can be handled by either recovery or treatment, this symposium is concerned with both approaches to the problem.

Reducing the Problem to Its Simplest Form

Before considering treatment or recovery as such, however, the steps which a plant should take to reduce a chromium or other metal-finishing wastes problem to its simplest and soundest engineering form will be briefly outlined. This approach consists first of defining the problem and second of reducing it to the maximum extent by steps short of treatment. It is not desired to be overly optimistic here about this approach, but some waste problems can be solved in this manner without the installation of recovery or treatment equipment.

Defining the Waste Load

The actual quantity of water leaving each sewer and its analytical characteristics must be determined in defining the problem. The quantity of effluent leaving the plant can be determined in a number of ways, including the installation of a weir in the sewer or meters on the influent to the operations in which the effluent has its origin. Sampling should be done over the same period that the discharge is being determined and the period should be long enough to be representative. Individual sample portions should be collected frequently enough so a true picture of effluent conditions will be obtained. The samples collected should be proportioned to the flow and composited so they are representative. The collection of composite samples will greatly reduce the amount of analytical work necessary and will still yield results which are completely accurate.

Reducing the Waste Load

Once the problem has been defined, the exact location and magnitude of the chromium waste load is available.

* A symposium presented at 1953 Annual Meeting, New York Sewage and Industrial Wastes Assn.; New York, N. Y.; Jan. 22–23, 1953.

Armed with this information, the next effort should be in the direction of reducing the problem so that waste recovery or treatment can be eliminated or the size of such equipment can be reduced. A manual developed on this approach by the Metal-Finishing Industry Action Committee of the Ohio River Valley Water Sanitation Commission is available through the Commission.

A chromium, or almost any other metal-finishing waste problem, can be reduced and simplified by:

1. Reducing water usage and wastes discharged by effective rinsing through:
   a) The use of automatic or manual valves to tie the flow of rinse water to the actual flow of parts through the plating line.
   b) Setting accurate water requirements for each operation and insisting that the plant operate on these requirements. This step will not only reduce the waste problem, but also should be the basis for appreciably reducing water costs.
   c) The counter-currenting of rinse water so one rinse stream will do the work originally done by two or three such streams.
   d) The use of fog sprays where applicable.
   e) Maintenance of racks to keep them in good condition and free of incidental metal nodules.
   f) Proper design of rinse tanks.
   g) Practicing maximum uniformity in racking.
2. Reducing drag-out losses by:
   a) Installing save-rinse or dip-rinse tanks.
   b) Using drip boards, which drain back to the process tank.
   c) Reducing dragin and dragout by air blowoff, tumbling of work, or other means.
   d) Introducing a brief stationary drain period over the process tank.
3. Preventing leaks and losses by:
   a) Routine inspections to locate leaks.
   b) Using above normal solution level lines for filling process tanks.
   c) Using level control float valves where applicable.
   d) The use of storage tanks, sumps, or pits so located as to save concentrated baths in case of leaks.
4. Salvaging solutions for further use by purifying baths by one or more of the following procedures:
   a) Settling.
   b) Decantation.
   c) Low current density purification.
   d) Filtration.
5. Selling or exchanging baths which cannot be further used.
6. In some cases with a somewhat greater expenditure than would be involved in most other steps listed in this section, an evaporator can be procured and used to simplify a chromium problem. Such an evaporator would concentrate rinse water for recharge back to the process baths.

Treatment Specifications

Before proceeding with a discussion of recovery and treatment it is appropriate to briefly list chromium concentration levels in a plant effluent which will usually be acceptable to city and state regulatory agencies. The following concentrations have been developed through general usage and have reached a point where they are reasonably standard throughout the country:

1. Industrial wastes entering a city sewer system served by a sewage treatment plant should not exceed 5 p.p.m. in hexavalent chromium concentration.

2. Industrial wastes discharging into a stream should not exceed a chromium concentration of 0.5 p.p.m.

The point has now been reached in this presentation where the plant has defined its chromium problem and has completed the steps outlined to reduce it to a satisfactory level. In spite of exhausting the control, care, and good housekeeping approach to the problem, chromium ions of consequence are still being discharged in the plant effluent. When this point is reached the only remaining step available is that of designing and constructing necessary recovery of waste treatment equipment to solve the problem. The remainder of this symposium is concerned with recovery and treatment methods that can be used to solve a chromium problem.

It should be stressed, of course, that the proper treatment or recovery approach to any problem must be tailored to the specific problem.

II. Reduction of Chromium Wastes by Sulfur Dioxide

By H. B. Channon

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The information contained herein is drawn from experience of many years in the use and development of liquid sulfur dioxide in the reduction of chrome (bichromates) by the tanning industry. Here, hexavalent chrome is reduced to the trivalent form. Although the concentrations of chromic oxide in the chrome tanning liquors are considerably higher than those considered here, the characteristics and requirements of the reaction are essentially the same; a strongly acidic reducing agent is required.

The purpose of this paper is to present some of the values in connection with the use of sulfur dioxide, or rather liquid sulfur dioxide, the form in which it is available for the reaction. It is not intended to duplicate all of the statements made in previous articles on the subject, but to fill in the areas of information that apparently have not been touched upon in developing a case for sulfur dioxide. In all efforts to solve effectively and efficiently this problem of chromium waste, it should be borne in mind that this material is of strategic importance. Therefore, efforts to dispose of this waste should be directed toward producing sludges in a form that later can be more economically processed into valuable raw materials or chemicals.

A later paper in this symposium considers a process that effectively carries out direct recovery and re-use of these chromium residuals. Not all plants are large, neither do they have the chrome waste discharging in such quantities as to warrant the investment in such a type of recovery. Therefore, there is need for considering the problem at a level commensurate with smaller operations. Here, the volume of waste is relatively small, the plants themselves may not have sufficient capital for a large investment, and they are not warranted in expending excess amounts in handling a small effort of their manufacturing endeavor.

It might be conceded, therefore, that the use of reducing agents, such as ferrous sulfate, sodium bisulfite, and sulfur dioxide, concerns itself primarily with the smaller operations.

Flow Sheet of Process

The literature seems to indicate general agreement regarding the flow sheet of the process required for carrying out

the reduction of chromium waste with such reducing agents. To support this general agreement and summarize briefly, the problem divides itself logically into two divisions, so far as procedure is concerned; namely, a batch or continuous process for treatment.

Batch Process

In regard to batch procedure, collection tanks of suitable size to hold an 8-, 16-, or 24-hr. volume of flow comprise the first unit to be considered. Duplicate tanks should be made available so that while one is being used as a treating tank, the second can be used as a collection tank, and *vice versa*. In a treating tank of proper proportions, reducing agents are added quickly and the batch thoroughly mixed with suitable agitating equipment. The resulting slurry is then pumped into a settling basin. The settling basins required should be properly equipped with overflow facilities to carry the supernatant liquors to drains, stream, or lake.

Continuous Process

Under a continuous process, also, the collecting tank is of immense value. It should be equipped with an overflow to the treating tank and be of the proper size to hold an 8-, 16-, or 24-hr. volume of flow. This permits development of more uniform and constant residuals in the discharge to the treating unit or tank; it evens up the peak and low loads, both as to volume and as to residuals. The collecting tank is, therefore, an essential feature in the better performance and precision-like operation of automatic equipment in synchronizing the flow of chemicals with the flow of hexavalent chrome.

A reducing agent treating tank, an alkali treating tank, and a settling basin are used in series as subsequent units to the collecting tank. Weirs or overflow channels carry the solutions from one to the other, and finally discharge the supernatant liquor from the settling basin to drains, streams, or lakes.

The treating tanks should be equipped with suitable agitating equipment, and the discharge of chemicals into such treating tanks should, in general, be towards the bottom in each case. The inherent tendency for sulfur dioxide gas to rise when released into the solution at the bottom, in some instances can develop sufficient turbulence and circulation so that agitating equipment, in a properly designed treating tank, is not necessary. Here is an intrinsic value in the use of liquid sulfur dioxide. With a little ingenuity, the sulfur dioxide or the reducing agent, in solution, can be diffused or mixed with the chromate solution coursing through a suitable length of pipe. The reaction then takes place in the line and the chrome so reduced can be delivered directly to an alkali treating tank. In some instances such a device can replace a treating tank.

Conventional Reducing Agents

If ferrous sulfate, sodium metabisulfite, and liquid sulfur dioxide are considered as the more conventional reducing agents, the general flow sheet previously outlined is applicable in each case. The essential difference would be in the equipment used for applying the chemical. Because ferrous sulfate and metabisulfite are powders, suitable dry feeders, solution boxes, etc., are necessary. In the case of sulfur dioxide, since the gas is obtained directly from the containers and can be diffused into the chromium solutions as such, the use of additional equipment required for the others is eliminated. In all instances the automatic control and feeding of the chemicals can be carried out effectively.

An equitable comparison of the chemical properties of these reducing agents requires observance of their perform-

ance at some common pH range and dilution factor. Hexavalent chrome residuals have been experienced from as low as 10 to as high as 500 p.p.m. For the sake of comparison, however, examination of their action is restricted to concentrations of 100 p.p.m. or less. It is also found that the pH's of these solutions vary quite markedly, falling into a wide range of from 2 to above 8.5. It has been indicated that most of the wastes reported on are from plating operations, and that the bulk of these wastes will carry essentially a pH of 3. Therefore, it is assumed in the following comparisons that these same conditions exist.

Pricewise, the comparisons drawn herein assume that the cost of ferrous sulfate is $3.00 per 100 lb.; that of sodium bisulfite is $3.36 per 100 lb.; and that of SO_2 (liquid sulfur dioxide) is $6.35 per 100 lb. Freight is not considered.

Positive *vs.* Negative Radical Reductions

As previously stated, the effective reduction of hexavalent chrome under variable pH conditions stresses the use of a reducing agent that has marked acidic properties. The points of interest to be brought out in connection with Tables I and II are as follows:

TABLE I.—Oxidation-Reduction Characteristics for Selected Compounds

Original Compound	Normal Potential (mv.)	Reduced Compound
(*a*) Chromate to Chromic Sulfate		
$2H_2^+CrO_4^-$	1,330	$Cr_2^+(SO_4)_3^-$
(*b*) Radical Reductions		
$Fe^{++}SO_4^{--}$	770	$Fe_2^{+++}(SO_4)_3^{--}$
$NaH^{++}SO_3^{--}$	170	$NaH^{++}SO_4^{--}$
$H_2^+SO_3^-$	170	$H_2^+SO_4^{--}$

TABLE II.—Basicity[1] of Selected Compounds

Approx. pH	Basicity (%)	Chromium Comp.	Iron Comp.
<2	0	$Cr_2(SO_4)_3$	$Fe_2(SO_4)_3$
2.65	33	$Cr_2(OH)_2(SO_4)_2$	$Fe_2(OH)_2(SO_4)_2$
3.5–4	66	$Cr_2(OH)_4(SO_4)$	$Fe_2(OH)_4(SO_4)$
5–7	100	$Cr_2(OH)_6$	$Fe_2(OH)_6$

[1] By Scherlemmer method.

1. Normal chromic sulfate solution has a potential of 1,330 mv.

2. The reduction by the positive radical in the case of ferrous sulfate should be noted; the ferrous ion is converted to ferric. In the case of sodium bisulfite and SO_2 (sulfurous acid), reduction is carried out by the negative radical; that is, SO_3 is converted to SO_4.

3. The normal potential of ferrous sulfate is approximately 770 mv.; those of sodium bisulfite and sulfurous acid are essentially the same at 170 mv.

4. It should be pointed out that in the reduction of hexavalent chrome, sulfate is produced. Because of the fact that chrome sulfate is amphoteric, a number of basic forms are possible. The molecular arrangements of the OH and SO_4 groups are indicated at basicities of 0, 33, 66, and 100 per cent. Approximate pH's developed at these corresponding basicities are 2.65, 3.5 to 4, and 5 to 7, respectively.

It also should be pointed out that when the reduction is carried out by ferrous sulfate, the positive radical of the ferrous sulfate takes part in the reduction; that is, the Fe^{++} is converted to Fe^{+++}. In the case of sodium bisulfite or sulfur dioxide, the reduction is carried out by the negative radical; that is, the SO_3 is converted to SO_4.

Ferrous Sulfate

The apparent advantage of using ferrous sulfate, or the positive radical reduction, is that the ferrous sulfate may be available at a price low enough to overcome its greatest disadvantage—namely, its low reducing potential, particularly at pH 3 and above.

One of the main disadvantages is that the ferric ion present becomes a contaminant of considerable degree in the final precipitate or sludge deposited in the settling basins, etc. As pointed out earlier, one should ultimately consider the recovery of the chromic oxide available in these sludges. The presence of ferric hydroxide will materially frustrate attempts to economically recover the chromic oxide. As a result, it is probable that in a few years many plants will have all of their available storage facilities filled and it would then be disconcerting to learn that their type of sludge is not wanted or desired. That sludge would be left and not processed by waste recoverers, for one of the basic problems in connection with the recovery of chromic oxide from chromite ores is in the separation and removal of the iron.

Another disadvantage with the use of ferrous sulfate is in the fact that in solution its acidic properties are not high, particularly at the dilutions in question (Figure 1).

Ferrous sulfate has little if any reducing value with the chromate solution having a pH of 3 and above (Figure 2), its reducing potential being quite close to that of the chromate. With such solutions, to increase their reducing potential, before near theoretical amounts can be used, the addition of sulfuric acid is required to lower the pH. A procedure of this kind, of course, only increases the amount of alkali needed to precipitate the trivalent chrome in bringing the treated solutions back to a pH of 8.5.

The author is not acquainted with any successful users of ferrous sulfate. It is rumored, however, that as high as

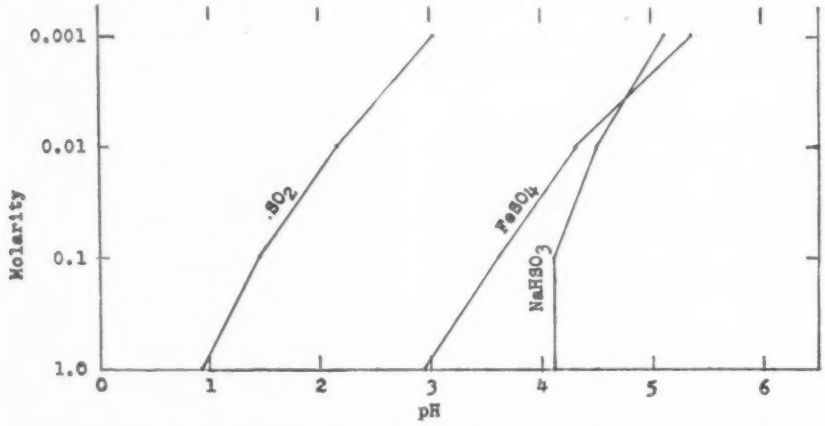

FIGURE 1.—Comparative pH values for various concentrations of SO_2, $NaHSO_3$, and $FeSO_4$.

Molarity	SO_2		$NaHSO_3$		$FeSO_4$	
	%	pH[1]	%	pH[1]	%	pH[1]
0.001	0.0064	3.02	0.0104	5.1	0.0142	5.35
0.01	0.064	2.15	0.104	4.5	0.142	4.3
0.1	0.64	1.47	1.04	4.1	1.42	3.6
1.0	6.40	0.91	10.40	4.1	14.2	2.9

[1] At 25° C.

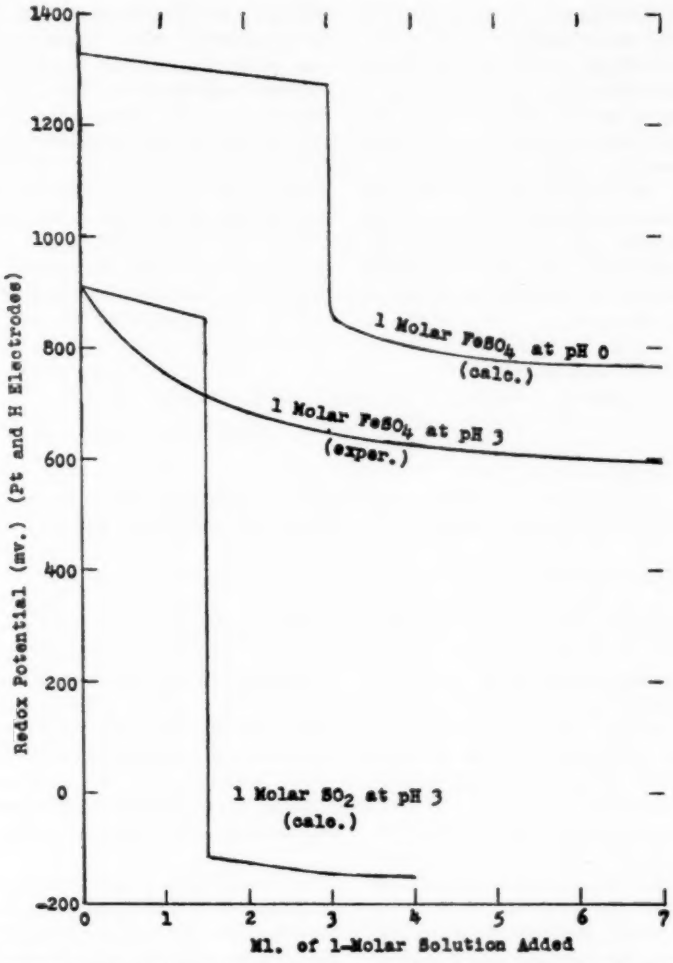

FIGURE 2.—Potentiometric titration of 0.1 g. CrO_3 per liter by $FeSO_4$ and SO_2.

2½ times theoretical amounts have been required. Again, it is not known in what pH range below 3 these were used. With such overcharges, the use of ferrous sulfate, of course, proves to be troublesome as well as expensive.

Bisulfite

When it comes to a comparison between sodium bisulfite and SO_2, the factors of differentiation are not so marked. In both instances the negative radical of the chemical is used for reduction purposes. In both cases, at a pH of 3, the reduction goes to completion quickly and without any difficulty.

An advantage of bisulfite over SO_2 may be its lower cost under batch operation. However, as is the case with ferrous sulfate, an excess over theoretical amounts is required for complete reduction.

In this connection it should be noted

that the first hydrogen in sulfurous acid, in the case of sodium bisulfite, has been neutralized. This is the more powerful and stronger of the hydrogen ions so far as acidity and potential are concerned. Consequently, at pH 3, even though sodium bisulfite effectively reduces the hexavalent chrome, the pH rises during reduction to terminate at an end point of pH 4.6. A chrome sulfate of rather high basicity (see Table II) is formed, in accordance with the following reactions:

$$2CrO_3 + H_2O = H_2Cr_2O_7$$
$$2H_2CrO_4 + 6FeSO_4 + 6H_2SO_4 = Cr_2(SO_4)_3 + 3Fe_2(SO_4)_3 + 8H_2O$$
$$Na_2Cr_2O_7 + 6FeSO_4 + 7H_2SO_4 = Cr_2(SO_4)_3 + 3Fe_2(SO_4)_3 + 7H_2O + Na_2SO_4$$

$$Na_2S_2O_5 + H_2O = 2NaHSO_3$$
$$2H_2CrO_4 + 3NaHSO_3 + 3H_2SO_4 = Cr_2(SO_4)_3 + 3NaHSO_4 + 5H_2O$$
$$Na_2Cr_2O_7 + 3NaHSO_3 + 5H_2SO_4 = Cr_2(SO_4)_3 + 5NaHSO_4 + 4H_2O$$

$$SO_2 + H_2O = H_2SO_3$$
$$2H_2CrO_4 + 3H_2SO_3 = Cr_2(SO_4)_3 + 5H_2O$$
$$Na_2Cr_2O_7 + 3H_2SO_3 = Cr_2(OH)_2(SO_4)_2 + 2H_2O + Na_2SO_4$$

The equations illustrative of the reduction by ferrous sulfate and sodium bisulfite clearly indicate the need for low pH's. Sulfuric acid is required when either chromic acid or sodium bichromate is reduced.

In the case of sulfur dioxide (sulfurous acid), the reduction goes to completion with both chromic acid and sodium bichromate. No sulfuric acid is required. In the reaction between SO_2 and sodium bichromate (at a pH of 4.5) a 33 basicity chrome sulfate is formed. The SO_2 (sulfurous acid) has sufficient acidity, which is lacking in the others, to cause the reaction to go to completion with theoretical amounts at these pH's.

The evidence indicates that it requires 75 per cent more than the theoretical amount of bisulfite to bring about complete reduction. As a result of these overcharges, bisulfite proves to be more expensive than SO_2 at $0.0635 per lb. On the other hand, it compares favorably with SO_2 at $0.10 per lb. (when liquid SO_2 is purchased in 150-lb. cylinders). Here again, as in the case of ferrous sulfate, the addition of sulfuric acid to lower the hexavalent chrome to a pH of less than 3 (probably to pH 2) will bring about a more efficient use of bisulfite. This is important when it is considered that although the theoretical amount of bisulfite required is 2.97 times that of the chromium, with 75 per cent excess the bisulfite requirement is 5.19 times that of the chromium. It also should be pointed out that the normal reducing potential of sodium bisulfite is essentially the same as that of SO_2. It is the rise in pH during the reaction that causes the potential to be dissipated rapidly, thus requiring excess amounts of chemical (see Tables I and II).

Sulfur Dioxide

Liquid sulfur dioxide presents both features for exploration—namely, the use of the negative radical for reduction purposes, and the stronger acidic properties of the positive side in lowering the pH effectively at the ranges desired by pH or redox end points. At pH 3 the reaction goes to completion with a slight lowering of pH at the end to 2.9. As the pH of the chromium solutions to be treated progressively rises above 3, the acidic properties of sulfur dioxide are more effectively brought into play. Here, it will continue to reduce the hexavalent chrome with theoretical amounts under pH conditions as high as 5.5. In this prop-

erty it displays in these higher ranges a decided advantage over the other reagents.

As the pH of the solutions under treatment rises above 5.5 to 8.5, the acidic properties of the sulfur dioxide can still be effectively used in lowering the pH into ranges where theoretical amounts from then on would be required. As the pH rises above 8.5, one has to determine whether or not it would be advisable to add a little sulfuric acid to neutralize the excess alkalinity. The theoretical amount of sulfur dioxide required is 184.5 lb. per 100 lb. of hexavalent chrome present.

Consideration of Basicity

Another aspect of the problem that has not been stressed is basicity. In the reduction that takes place with such reducing agents as have been mentioned, a chrome sulfate is formed. This material is amphoteric. It is in the interpretation of this property that the word "basicity" has been derived. The value of basicity, insofar as it concerns the problem under discussion, is in the realization that in basicities between 66 and 100 (Table II) much of the chromic oxide is precipitated.

An important economic consideration of basicity is that if reductions can be carried out so that the end point falls between pH 3 and 5, and these basic forms are developed, the amount of alkali needed later to raise the pH to 7 can be minimized greatly. It so happens that as the pH of chrome waste solutions rises above 3, and SO_2 is used, these more basic forms result. One can conclude, therefore, that sulfur dioxide offers greater flexibility in coping with these solutions.

Summary

1. In coping with chrome wastes collecting basins are of great value in smoothing out fluctuations of chromium concentration and pH, enabling closer determination of the quantities of reducing agents required and reducing the excess requirements when sodium bisulfite and ferrous sulfate are used.

2. At pH 3, at a dilution factor of 100 p.p.m. Cr, little if any reaction takes place in the reduction of hexavalent chrome with ferrous sulfate. Appreciable amounts of sulfuric acid would be required to lower the pH to 2 before reduction will take place with anywhere near theoretical amounts.

3. With bisulfite, the reaction goes to completion with a rise in pH to about 4.6, requiring about 75 per cent in excess of theoretical proportions. Lowering of the pH by addition of sulfuric acid is required to bring about reaction with essentially theoretical proportions.

Sulfur dioxide reacts quickly and completely with theoretical proportions, with a slight lowering of the pH to about 2.9.

Theoretical proportions of sulfur dioxide are used in ranges of pH higher than 3, and up to and including 5.5. In such ranges more basic forms of the chrome sulfate are formed, which would decrease the amount of alkali required to precipitate the trivalent chrome.

In ranges higher than 5.5, and up to 8.5, sulfur dioxide can still be used, if desirable, to neutralize the alkalinity in reducing the pH to 5.5 or less, where theoretical proportions would be used. In ranges higher than 8.5 the advisability of using sulfuric acid to lower the pH range below 5.5 should be considered in cutting the cost of a sulfur dioxide treatment.

Sulfur dioxide effectively reduces hexavalent chromium at pH 1 to 5.5 with theoretical proportions. At pH 3 to 5.5, however, sulfur dioxide proves to be a more economical reducing agent than either ferrous sulfate or sodium bisulfite. This is by virtue of its strongly acidic property and higher reducing potential.

III. Instrumentation in Chromium Waste Treatment

By W. N. Greer

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Although oxidation-reduction (redox) potential measurements have been applied to various industrial processes for many years, the real significance of the potential values is probably understood by relatively few users. A number of papers have been presented on the application of redox in the reduction of chromium in industrial waste treatment, but the author has noted only one (1) in which data have been presented relating potential values to the reducing agent involved. The chemical reactions and their incorporation in the oxidation-reduction relations should give information on the potential values to be encountered, and the relation between potential change and the percentage excess of the reducing agent.

Without attempting, if it were possible, to describe the mechanism whereby a potential is developed at the surface of a suitable electrode (platinum is usually used) when it is immersed in a solution containing a reducing substance and its oxidation product (or *vice versa*), suffice it to say that the potential between platinum (or other suitable unattackable electrode) and a suitable reference electrode, such as a calomel electrode, in such a system is a measure of the ratios of the concentrations of the reductant and the oxidant.

In an acid solution of ferrous and ferric sulfates, the relation found is given by

$$E = E_0 + \frac{RT}{nF} \log \frac{[Fe^{+++}]}{[Fe^{++}]} \ldots (1)$$

The general form of this equation is

$$E = E_0 + \frac{RT}{nF} \log \frac{[Ox]}{[Red]} \ldots . (2)$$

in which E_0 is a constant characteristic of the particular oxidation-reduction equilibrium being measured, R is the gas constant, T is the absolute temperature, n is the number of electrons involved in the transformation of the oxidant to the reductant, and [ ] represents molal concentration. At 30° C., $\frac{RT}{F} = 0.06$.

Examination of Eq. 2 shows that $E = E_0$ when $\frac{Ox}{Red} = 1$. Also, that the measured potential will vary 60 mv. when $n = 1$, or 30 mv. when $n = 2$, for every 10:1 change in the ratio of the concentration of the oxidant to the reductant. The value of E_0, if not known, must be determined experimentally. It is of interest in calculating the theoretical equivalence point, or in calculating the potential for a given percentage excess of reducing or oxidizing agent.

Reduction of Hexavalent Chromium

Hexavalent chromium in the form of chromic acid, chromate, or dichromate in an acid solution is reduced to trivalent chromium by ferrous sulfate, sodium metabisulfite, or sulfur dioxide. The trivalent chromium is later precipitated in the treatment process in an alkaline medium.

Ferrous Sulfate

The oxidation-reduction reaction with ferrous sulfate can be expressed by

$$Na_2Cr_2O_7 + 6\ FeSO_4 + 7\ H_2SO_4 \rightleftarrows Cr_2(SO_4)_3 + 3\ Fe_2(SO_4)_3 + 7\ H_2O + Na_2SO_4 \ldots (3)$$

in which ferrous sulfate reduces bi-

chromate and is itself oxidized. In terms of oxidation-reduction, the reactions are:

$$6\ Fe^{++} \rightleftarrows 6\ Fe^{+++} + 6\ e \quad \ldots (4)$$

$$Cr_2O_7^{=} + 14\ H^+ + 6\ e \rightleftarrows 2\ Cr^{+++} + 7\ H_2O \quad \ldots (5)$$

in which e represents an electron.

The potential relations for these reactions are given by:

$$E = 0.469 + \frac{0.06}{6} \log \frac{[Fe^{+++}]^6}{[Fe^{++}]^6} \quad \ldots (6)$$

and

$$E = 0.902 + \frac{0.06}{6} \log \times \frac{[Cr_2O_7^{=}]}{[Cr^{+++}]^2} [H^+]^{14} \quad \ldots (7)$$

Relative to the expression for the potential of the chromium system, it should be noted that the potential should change 0.140 volt for each pH variation, inasmuch as this potential equation can be written

$$E = 0.902 + 0.01 \log \times \frac{[Cr_2O_7^{=}]}{[Cr^{+++}]^2} - 0.14\ pH \quad \ldots (7a)$$

Actually, the potential change is somewhat less than this. Kohltoff (2) states that the behavior of the bichromate electrode has not been explained from a theoretical point of view, and it is impossible to make exact calculations. The E_0 value of 0.902 volt previously given was calculated from Kohltoff's determination at pH 2 corrected to 30° C. The value of E_0 then, at pH 2, is 0.622 volt. The experimental value of E determined from the data of Kelch and Graham (1) is 0.590 volt at pH 2, and 0.555 at pH 2.5.

At the equivalence point,

$$\frac{[Ox_1]}{[Red_1]} = \frac{[Red_2]}{[Ox_2]} \quad \ldots (8)$$

and

$$E = E_0' + 0.06 \log \frac{[Ox_1]}{[Red_1]} = E_0'' + 0.06 \log \frac{[Ox_2]}{[Red_2]} \quad \ldots (9)$$

where Ox_1 is the oxidant being treated with the reductant Red_2 and, of course, Red_1 is the reduction product of Ox_1, and Ox_2 is the oxidation product of Red_2. E_0' is the normal potential of the system $Ox_1 \rightleftarrows Red_1$, E_0'' that of the system $Ox_2 \rightleftarrows Red_2$.

The equivalence potential, from Eqs. 8 and 9, is

$$E = \frac{E_0' + E_0''}{2} \quad \ldots (10)$$

From the general equation—

$$a\ Ox_1 + b\ Red_2 \rightleftarrows a\ Red_1 + b\ Ox_2 \quad \ldots (11)$$

—it can be developed that the equivalence potential is

$$E_E = \frac{b\ E_0' + a\ E_0''}{a + b} \quad \ldots (12)$$

From Eqs. 4 and 5 of the chrome-ferrous sulfate system, at pH 2,

$$E_E = \frac{6 \times 0.622 + 2 \times 0.469}{8} = 0.581.$$

Kelch and Graham (1) report a value of 0.537 volt.

The magnitude of the potential change in passing through the equivalence point is dependent upon the normal potentials of the two oxidation-reduction systems that are involved. The potential that will exist for a given excess of reductant can be calculated from

$$E = E_0'' + \frac{0.06}{n} \log \frac{[Ox_2]}{[Red_2]} \quad \ldots (13)$$

For the ferrous-ferric system in the reduction of chrome, Eq. 6 is applicable. For 10 per cent excess of reductant, $E = 0.469 + 0.06 = 0.529$. The Kelch and Graham data (1) give a value of approximately 0.495.

Control of the redox potential at 500 mv., with ferrous sulfate as the reducing agent, should, therefore, assure complete reduction of the chrome. Sufficient sulfuric acid should be present to satisfy the chemical reaction and give a pH somewhere between 2.0 and 2.5. In addition it should be noted that the potential changes 60 mv. for every 10 to 1 change in the ratio of the oxidant to the reductant, at a constant pH.

Metabisulfite

The redox potential at which a small excess of metabisulfite exists in the chromate reduction system is about 380 mv. at a pH of about 2.5. The same general considerations apply in the system as in the ferrous iron system in that the pH should be maintained at some set value. The break in potential at the equivalence point is of a greater magnitude than with the iron system, giving greater sensitivity of measurement in terms of reagent used.

Sulfur Dioxide

The theoretical normal potential of the sulfite system has been given as 0.045 volt, which indicates that a 10 per cent excess of the reductant would give 0.105 volt, or a 1 per cent excess 0.165 volt.

These data indicate a potentially better reducing agent in SO_2.

Layout of Treatment Process

It is dangerous to generalize on the layout of treating systems where pH and redox control are to be applied. It is fortunate that the pH values at which these reductions are carried out is low (2 to 2.5), making the problem of pH control not too difficult. The redox control will be influenced chiefly by chrome concentration and flow rates. In order that these might not fluctuate too rapidly, the normal procedure is to introduce a holding capacity ahead of the treatment. The size of this holding tank could be influenced by plant operating procedures, but might have a 1-hr., or perhaps 2- or 3-hr. holding time. This would be followed by the redox reaction chamber, well agitated, which might have a holding capacity of 10 to 30 min.

Figure 1 shows the schematic layout of the treating system described by Gard, Snavely, and Lemon (3). On the chromium reduction system, and not indicated in Figure 1, pH control would normally be applied to the

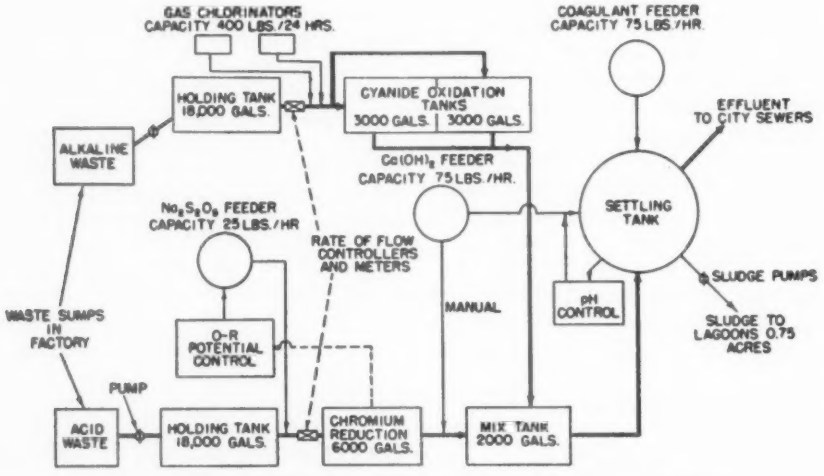

FIGURE 1.—Schematic flow diagram of chrome waste treatment plant (3).

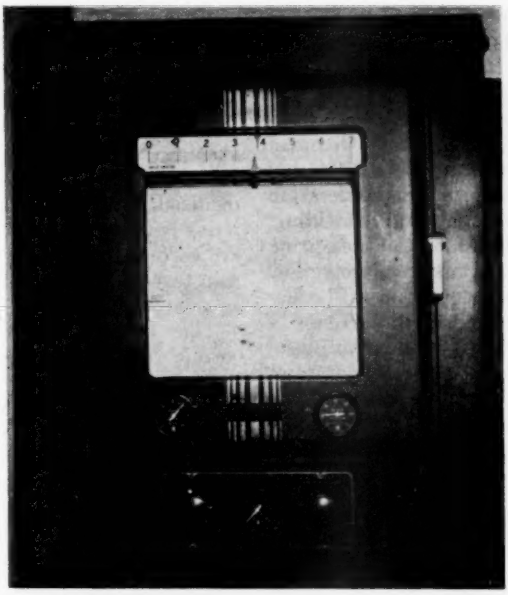

FIGURE 2.—Redox potential recorder-controller with pneumatic positioning of sodium metasulfite feeder.

reduction reaction tank. In most cases this would be sulfuric acid control, although in those plants having waste pickle liquor, use would no doubt be made of it, thereby gaining at least partial reduction from the ferrous sulfate in the pickle liquor.

Also, the normal procedure would be to apply pH control at the mix tank, rather than in the settling tank as indicated in Figure 1, to give the alkalinity required for precipitation of the chromium.

If redox control is not to be applied, much greater holding capacities would be required and the waste should be delivered to the reaction chamber at a fixed rate. The other alternative is to treat batchwise, in which case two treating tanks of suitable capacity would be required.

Advantages of Redox Control

Since the redox potential is related to the ratios of the concentrations of oxidant and reductant, and not to the actual concentrations, automatic redox control adjusts the feed of reducing agent to the set end point regardless of the chromium concentration. It is appreciated, of course, that a rapidly fluctuating chromium concentration would upset the control, but properly sized holding and reaction tanks would provide a waste solution in which the rate of change of chromium concentration would not exceed that at which control within prescribed limits could be maintained.

Under automatic control, it should be possible to continuously treat the waste to give a treated effluent meeting required specifications. There might be some economy in avoiding excessive use of chemicals, and possibly in labor, but these are factors that would be influenced by operations existing under these two conditions.

Control Equipment

Measuring and controlling devices for redox potentials and pH have been

described in numerous papers and complete descriptive material is available from the various manufacturers of such devices. Suffice it to say here that pH measuring devices, when operating with the glass electrode, must be designed to operate on high external impedance with proper consideration given to insulation and shielding, whereas the redox potential measuring devices, operating at relatively low impedance, must, nevertheless, be designed to draw very small currents in order to avoid electrode polarization.

Figure 2 shows a redox potential recorder-controller, pneumatically positioning a metabisulfite feeder. The chart indicates that the potential is maintained within about ± 5 mv. of the set potential, indicating close control of the bisulfite feed.

Various controlled feeding devices, such as valves, pumps, chemical feeders, and slurry cutting boxes, operated from pH and redox controllers, are available to feed the various reagents used in treatment. The type of device to be used is determined by the reagent to be used and the conditions under which it is to be fed to the system.

Essential to the satisfactory control of any process of this type, however, is the proper physical layout of the treating system, as has been previously noted (4). Fundamentally, the treating system is a part of the over-all control equipment.

Other Waste Redox Control Possibilities

There are other waste problems that may well be controlled from redox potentials. Treatment reactions involving chlorine, in which objectionable waste products may be chlorinated or oxidized, offer control possibilities for redox potentials. As an example, there are certain dye products, such as certain textile dye wastes, which might be so treated.

The bacteriological treatment of certain organic wastes wherein the oxygen demand or excess oxygen may be controlled from the redox potentials, has been indicated in some recent publications.

Other possibilities no doubt will be encountered as the waste problem is further studied and the use of redox potentials is better appreciated.

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IV. Chromic Acid Recovery by Ion Exchange at Grumman Aircraft

BY DURWARD T. ARMSTRONG

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In 1949, Grumman Aircraft Engineering Corp. was confronted with the possibility of enlarging its chromic acid disposal facilities. Included in the material studied during the survey was Costa's paper (1) on the decationization of chromic acid anodizing baths, and which awakened the realization of the potential that reclamation would have toward reducing the disposal

problem. In the ensuing pilot operations one further step was taken—namely, the investigation of the possibilities of concentrating the chromates from the rinse waters on strongly basic anion resins. The results warranted purchasing ion exchange equipment for the purpose of completely demineralizing and recirculating the rinse waters from one of the 3,600-gal. production anodizing installations.

In this particular case the rinse waters are recirculated through a 10-cu. ft. bed of a strongly basic anion cell and back to the rinse tank via a 10-cu. ft. cation exchanger. The chromic acid is concentrated on the anion resin during the first stage of demineralization and the aluminum and other positive ions are removed by the cation resin. This is a closed system; no chromic acid enters the waste lines.

At present the exchanger effluents during regeneration are being treated at the previously established disposal facilities. In this way, 500 gal. of a 0.5 per cent solution of chromic acid are being destroyed as a batch, rather than 50,000 gal. from a continuous overflowing rinse. The anion capacity for hexavalent chromium is approximately 2.5 lb. per cubic foot. Thus, during each cycle about 25 lb. of chromic acid is concentrated from the rinse waters.

The disposal problem can be further reduced through decationization of the sodium chromate effluent during regeneration of the anion cell. In this way it is possible to return the chromic acid from the rinse tanks for replenishing purposes.

Savings Realized

The value of the 25 lb. of chromic acid concentrated on the anion bed per cycle will more than pay for the resin and chemical used for regeneration of the cation cell. Actually, the resin cost represents less than 20 per cent of the value of the chromic acid being concentrated at this stage. In this case the cost of decationization is more than offset by the cost of destruction, wherever reduction and neutralization is required.

Savings are realized at this stage, however, due to the fact that water is used only to compensate for evaporation losses and dragout. The former overflow rate was 1,000 g.p.h., which represented 2 m.g. of water per shift per year. To this could be added the differential in the cost of heating the bath. The amount of steam required to heat the tank is considerably reduced, inasmuch as the recirculation is accomplished with only a slight drop in temperature.

The concentration of chromic acid in the anodizing baths ranges between 8 and 12 oz. per gallon, and the pH is maintained between 0.7 and 0.9. During the anodizing operation approximately 0.5 lb. of aluminum is thrown into the bath for every 1,000 sq. ft. of material being processed. The aluminum combines with the hexavalent chromium and effects a rise in pH. The concentration increases as chromic acid is added to maintain the pH. When the concentration reaches the upper limit the bath is cut back by drawing off between 25 and 50 per cent of the bath.

It is no longer necessary to make these periodic drawoff increments every three or four months. Instead the pH of the anodizing bath is maintained through decationization. This is accomplished by passing the anodizing solution directly through a 10-cu. ft. cation cell, where an exchange of aluminum ions for hydrogen ions takes place. It is interesting to note that the desired pH can be maintained with no increase in total chromic acid concentration, and with an actual decrease in the concentration of aluminum ions. The concentration limits are still maintained between 8 and 12 oz. per gallon, as such baths are most economical to operate. The concentration of free acid averages between 15 and 20 per cent of the total chromic acid.

TABLE I.—Operational Costs, per 8-Hr. Shift

Ion Exchange Method	
1. Cation resin, based on 250 cycles	$1.20
2. Anion resin, based on 100 cycles	7.50
3. Sulfuric acid regenerant, 100 lb.	2.50
4. Caustic soda regenerant, 40 lb.	2.00
5. Water for regeneration, 2,000 gal.	0.20
6. Total chemical costs	$13.40
7. Reclaimed chromic acid, 50 lb.	15.00
8. Reclaimed rinse waters, 10,000 gal.	1.00
9. Total credits	$16.00
10. Net savings of this method	2.60
11. Net savings of this method	7.10[1]
Chromic Acid Disposal	
1. Chromic acid, 50 lb.	$15.00
2. Sodium bisulfite, 100 lb.	6.78
3. Sodium hydroxide, 50 lb.	2.75
4. Water, 10,000 gal.	1.00
5. Total chemical	$25.53
6. Ion exchange method credit	2.60
7. Disposal method deficit	25.53
8. Net savings ion exchange *vs.* disposal	$28.13
9. Net savings ion exchange *vs.* disposal	32.63[1]

[1] Based on an anion life of 250 cycles.

It is not necessary to decationize 15 per cent of the bath. In fact, about 50 lb. of chromic acid are freed per cycle, which represents between 2 and 3 per cent of the total concentration in this particular case. The pH is lowered approximately 0.05 per cycle. About 9 lb. of aluminum are removed per cycle, enabling processing of more than 20,000 sq. ft. of material.

More than 5 lb. of chromic acid are tied up per hour during anodizing, and the value of the reclaimed acid is four times the value of the sulfuric acid regenerant and resins based on 250 cycles. The cost saving can be applied to amortization and maintenance of the equipment. The cost of the resin in this instance is only 8 per cent of the value of the recovered chromic acid. Based on 250 cycles, the total saving through decationization would be about $2,800.

The economy of this stage more than absorbs the cost of resins and regeneration chemicals for both the anion and cation units, even if the life of the anion resin is limited to 100 cycles (see Table I). The net savings based on 250 cycles for the cation resin and 100 cycles for the anion resin would be 45 per cent of the value of the chromic acid recovered through decationization. This would amount to about $1,700 over a period of one year.

Chromic acid anodizing is an ideal subject for ion exchange techniques. In the first place, the concentrated 10 per cent bath can be decationized directly with the sulfonated styrene-type resins. This condition is supplemented by the high "throwing" power of the bath over a wide range of concentration for both free and combined acid. This adaptability is carried over to the rinsing stage.

Through continuous demineralization, the chromic acid concentration of the rinse tank is maintained at between 10 and 50 p.p.m. This concentration range permits time out while the anodizing bath is being treated. Thus, there are several degrees of freedom peculiar to anodizing which make ion exchange essential where any real volume is involved. Demineralization effects a cost savings and at the same time gives a higher quality product with operational consistency. Certainly, if there is any question of a water shortage or a disposal problem, ion exchange is the best answer to date for chromic acid anodizing solutions.

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WORKABLE INDUSTRIAL WASTE CONTROL *

By Norman W. Anderson

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Some months ago, a discussion with a fellow engineer pointed out the problems of making any industrial waste control really workable. Dealing with industrial waste is like looking in one's favorite bridge book to see what to bid on a particular hand, and, as usual, finding that it doesn't quite include your combination of cards. A simple, rigid policy would provide the easy way out, at least for those charged with administration of a standard. It is hardly workable, however, when viewed from industry's position.

Six group headings are offered herein as a basis for outlining an industrial waste standard. Experience indicates the need for maximum flexibility, consistent with regulations that protect the longevity of the system, and the maintenance personnel, and which do not increase operation and maintenance cost excessively. The many variables involved were brought more sharply into focus with the formation of an informal committee that met a little over a year ago in an attempt to present a more uniform policy to industry in the Los Angeles area. Those in attendance at these meetings represented the cities of Los Angeles, Long Beach, and Vernon; the Industrial Waste Division, Los Angeles County Engineer's office; the Orange County Joint Outfall Sewer; and the County Sanitation Districts of Los Angeles County. Richard D. Pomeroy, Consulting Engineer, Pasadena, was instrumental in organizing this group and contributed considerable time and effort in its work. Some modifications in exisiting policies were resolved and considerable thought was provoked in all who attended.

Prior to developing an outline for industrial waste standards, the three main factors affecting such a standard should be considered, as follows:

1. Type of system—whether separate or combined,
2. Type of treatment—whether primary or secondary,
3. Method of disposal—ocean, river or lakes, land, water reclamation; reaction of local authority.

The divisions are broad in scope and it is evident that much overlapping and interdependence of factors will exist. For example, considering the type of system, the combined system would probably not require the exclusion of cooling water in an industrial waste discharge. In a large system it may be possible to accept a particular waste in a large trunk that could not be successfully handled by a small local line. A sewer plant utilizing secondary treatment would be concerned over a waste that would have an adverse effect on the biological oxidation process. When considering inorganic wastes, the factor of final disposal is primarily one of dilution.

One must recognize that even the divisions shown under final disposal can vary widely. Disposal to the Los Angeles River would be similar to direct land disposal, whereas discharge to the Columbia River might provide a dilution similar to a well-placed ocean outfall. Close cooperation with the authorities having control over sewage plant effluents will provide a background as to how this factor will affect the ultimate standards.

* Presented at 1953 Annual Meeting, California Sewage and Industrial Wastes Assn.; Santa Barbara, Calif.; Apr. 22–25, 1953.

The six main divisions serving as a basis for formulating an industrial waste standard are as follows:

1. Method of connection.
2. Segregation of unwanted wastes.
3. Wastes causing structural damage.
4. Wastes containing oil and grease.
5. Wastes with high B.O.D.
6. Toxic wastes.

An attempt has been made to set up these groups in their order of recurrence; however, some change in order may be advisable for a particular system. The method of connection must be considered in each application.

To facilitate testing and control, industrial wastes should be segregated, and this segregation should be complete, at least to a point where sampling is possible. Although not anticipated, this provision further places the sewerage authority in the position of having control over the industrial waste discharge; suspension could be ordered without depriving a plant of its sanitary facilities. Segregation of storm waters must be obtained for a separate system, although dry weather spillage and leakage from open air industrial processes must go to the sewer if ground water pollution or contamination is a possibility.

Under the second group (that is, segregation of unwanted wastes), provision can be made to exclude such materials as are normally foreign to a system. Included in this would be any material that would settle out in the sewer, such as sand, metal filings, and heavy sludges. In the case of a separate system, one must be equally concerned with water that might be too good for sanitary sewer discharge; that is, cooling waters. Sewer capacity must be jealously guarded; close cooperation with industry will effect a maximum re-use of waters.

Wastes that are damaging to sewer structures are most generally acid wastes. Wastes containing dissolved sulfides or wastes which readily produce sulfides should be included in this group, as acids that cause considerable damage are formed from sulfides above the water surface in sewers. The Sanitation Districts of Los Angeles County stipulate a minimum pH of 6 for waste discharge. No upper limit is set, providing incrustation of the sewers does not result. The maximum allowable dissolved sulfide content of a waste is set at 0.1 p.p.m. Alkaline wastes are generally beneficial, as they permit a higher concentration of sulfides to be held in solution; conversely, the lowering of the pH of sewage by the addition of an acid waste may result in the release of hydrogen sulfide gas. A toxic atmosphere can result and extreme caution is necessary to protect maintenance personnel.

Oils and grease are becoming a more perplexing problem. With the increased use of detergents and emulsifying agents in the home as well as in industry, a more realistic approach is required. The average grease content of domestic sewage is increasing and it seems unreasonable to impose on industries limits that are impossible to achieve from a home discharge. The Sanitation Districts of Los Angeles County have found it advantageous to classify oils and grease as either floatable or dispersed. For industries with large volumes of waste containing hydrocarbon oils, the floatable oil content is limited to 10 p.p.m. Wastes containing vegetable or animal oils may be allowed with concentrations up to 25 p.p.m. A well-emulsified or dispersed oil will normally be allowed up to 600 p.p.m. The emulsion must be stable and not break by dilution or a limited change of pH. In any large sewer system, it is doubtful if the average content of oils and grease in the sewer can be materially changed by industrial contribution under reasonable control. To effect disposal of oils and grease to the sewer by the use of emulsifying agents should not be allowed. The fairness of a higher standard for dispersed oils and

grease is apparent if a spot check of dishwater is indicative of some domestic wastes. The modern housewife using a detergent can easily discharge dishwater containing 6,000 p.p.m. of grease prior to dilution with other household wastes. If the frying pan were forgotten on the stove and washed separately with about a pint of hot water and a little detergent, this increment of waste could contain 30,000 p.p.m.

Concern for waste with a high B.O.D. would probably be greater in a small system than in a large one, as the percentage increase in treatment plant load would be greater. A distribution of this extra cost between industry and the sewerage authority might be necessary. Further discussion of sewerage charges is beyond the scope of this paper, but attention is directed to the many reports on this subject that have been presented in the literature from time to time. As a personal opinion, the author urges caution in using too rigorous a formula in equating the total load of the industry and its assessed valuation to the corresponding factors for the community or authority. Consideration should be given to other factors, such as the number of employees and the value of the product to the community.

Experiences with wastes containing toxic materials are less frequent than others, but certainly not less important. This group, more than any other, is influenced by the three basic factors mentioned previously. In particular, the point of disposal is most important. Obviously a system with ocean discharge can tolerate material that should not be directed to ground-water and irrigation systems, or to a lake or river that does not provide sufficient dilution. Close cooperation with the agency concerned with such discharges would best provide the background for setting standards under this category.

Compounds that may give off toxic or flammable gases (that is, gasoline or aromatic cleaning compounds) should not be permitted in any waste discharge. Wastes containing cyanide should be controlled; the Sanitation Districts have set a maximum concentration limit of 10 p.p.m.

No standard for a waste containing phenols is suggested, as the type of treatment, as well as the point of discharge, plays a major role. The thought of a chlorinated phenol invokes fear in many a waterworks man, yet this type of waste has been successfully treated in a plant using sedimentation, a trickling filter, and chlorination (1).

The need for flexibility in judgment when considering toxic wastes is most important. "What is one man's meat might be another man's poison," a case in point being an experience of the Sanitation Districts of Los Angeles County. A large chemical industry was treating a copper-ammonium-acetate waste for the separation of copper so that the waste could be safely discharged to an unimproved natural drainage channel. The Sanitation Districts were able to accept this waste without pretreatment and because of its ability to change soluble sulfide to an insoluble form this waste became an asset in the control of sulfides. Were this same waste tributary to a small plant with land disposal, a limitation on the copper content might be necessary to guard against possible ground-water pollution, and protect biological plant processes.

A discussion of radioactive wastes is beyond the scope of this paper. Nevertheless, the following may be said in general about this type of material. To the author's knowledge, those working with radioactive materials are well versed in the problem of disposal as a condition of obtaining the material. The advice and guidance of these people should be sought. Points of discharge should be known and a monitoring program covering major sewers activated. This program can serve as a check on these discharges and further indicate the required points of sewer

cleaning to prevent dangerous build-ups.

Although caution is urged, fear is no substitute for actual experience. Close cooperation with industry and industrial consultants, if any, can many times solve an otherwise onerous problem. Special treatment or trucking of an undesirable waste can be most expensive. It is possible that industry can more economically underwrite the expense of fairly detailed experimentation programs. Dosages of questionable wastes can be varied and the various components of a treatment plant, as well as the trunk sewers, checked for performance, and a waste tolerance thus determined. An interesting example of this was experienced with the discharge of refinery waste to the Sanitation Districts' system. In reviewing this proposed discharge, considerable concern was expressed by the Districts' personnel, industry's consultant, and refinery staff itself of the possible effect of that part of the waste containing sulfonates. Segregation was possible and the refinery staff had reluctantly resolved the thought that they would truck this component away for separate disposal. As finally arranged, the entire waste was accepted on a trial basis, with the industry agreeing to submit monthly reports for a period of 6 months covering any possible influence on the sedimentation and digestion processes of the Districts' treatment plant. The effect upon the receiving trunk sewer was also studied. This particular discharge has been accepted by the District without incident for some time.

In closing, it is recommended that discharge permits be subject to review as conditions change. However, for good relations, this prerogative should not be exercised except when absolutely necessary.

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CONSTRUCTION REPORT FOR FIRST QUARTER OF 1953

Contracts totaling $31,000,000 were awarded during the first quarter of 1953 for 119 sewage treatment projects, serving an estimated 4,943,000 people, according to a recent report of the U. S. Public Health Service. Of these projects, 61 are for construction of new sewage treatment plants, 48 are for enlargement or improvement of existing plants, and 10 are for construction of interceptor sewers. Largest of the new plants is that for Woodbridge Township, N. J., costing $3,478,000.

The $31,000,000 investment represents a slight increase over the 1952 expenditures for the same period, but is said to be far below the amount needed to conserve the nation's clean-water resources. By major drainage basin, the number of projects undertaken during the period is as follows:

Drainage Basin	No. of Projects
Northeast	1
North Atlantic	9
Southeast	11
Tennessee	1
Ohio	14
Lake Erie	3
Western Great Lakes	3
Upper Mississippi	13
Missouri	10
Southwest-Lower Miss.	10
Western Gulf	21
Colorado	2
Great Basin	3
California	11
Pacific Northwest	7
Total	119

RECENT DEVELOPMENTS IN DESIGN OF SMALL MILK WASTE DISPOSAL PLANTS *

By J. P. Horton and H. A. Trebler

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Unlike most other industries that have a serious waste disposal problem, the dairy industry is faced with the prospect of having to erect a large number of relatively small treatment plants for country milk receiving stations or small processing plants not on or near municipal sewer systems. Because of their rural locations, the streams to which these plants discharge their wastes frequently are good fishing streams, so that there is considerable pressure to eliminate pollution.

Many country receiving stations, although presently increasing in size, are very small by most manufacturing standards, receiving only 30,000 to 60,000 lb. of milk per day and employing only two or three men. The magnitude of the waste disposal problem of each plant is also small by most waste treatment plant standards. Table II gives some examples of the waste volume from a few plants of associated companies in Pennsylvania. In some locations, milk processers have been required to build treatment plants to take maximum waste volumes as low as 2,000 g.p.d. and maximum B.O.D. loads as low as 5 to 10 lb. per day. This may seem somewhat absurd to some people, but may be necessary as part of a program leading to uniform law enforcement for small and large alike.

From a technical point of view, many of these small plants do an excellent job of waste saving and might well be left alone, because their wastes are oftentimes of more benefit than harm to the fish population. Milk is an excellent food both for human and aquatic life, and so long as the proper aerobic conditions are maintained in the stream at all times, milk solids are actually of benefit. An interesting series of articles by Pien (1) gives a wealth of data on aeration of milk waste under simulated stream conditions. The results indicate that, wherever sufficient dilution is available to reduce the B.O.D. to 20 to 30 p.p.m. in a fairly shallow stream, natural stream reaeration will always be able to maintain at least 50 per cent of the D.O. at saturation, even if there is very little turbulence. On the basis of the results, Pien makes a good case for the use of more sanity and common sense in evaluating a stream's ability to handle small amounts of nontoxic organic wastes.

Treatment plants for milk receiving stations or small processing plants not only must be low in cost, but also must be very simple to operate because small operators cannot afford to hire special personnel for maintenance. In some cases, plants receive as little as 5 min. attention per day. Although this is not desirable, or even satisfactory, it is a factor that must be taken into account in the design of these units.

Waste Saving

As frequently stated (2)(3), it is more economical to stop waste at its source than to treat the waste in disposal units. However, it is often difficult to convince employees who have been working in milk plants for many

* Presented at 8th Industrial Waste Conference, Purdue University; Lafayette, Ind.; May 4–6, 1953.

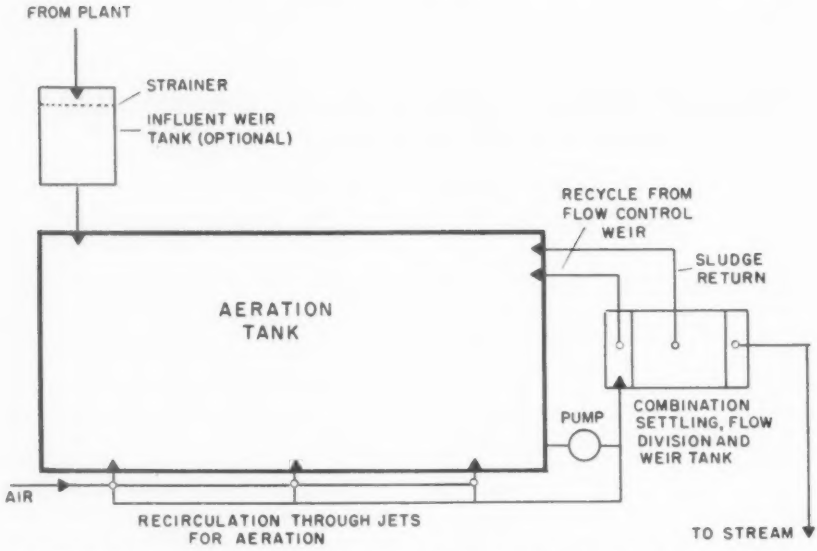

FIGURE 1.—Basic flow sheet for small dairy waste treatment plants of the activated sludge type.

years that a few drops of milk here and there can produce a serious pollution problem. The educational approach to waste elimination is far more important than the modification of equipment or the construction of treatment units. Excellent progress is being made in this direction. Nevertheless, waste treatment units still have to be built, even if they are much smaller in size than they would have been without the wastesaving efforts.

During the last year or two, several small waste disposal plants have been built in Pennsylvania by the associated companies. These treatment plants have followed the simple basic plan shown in Figure 1. Design data for four small waste disposal units of this type are given in Table 1.

TABLE I.—Typical Design Data for Small Dairy Waste Treatment Plants

Plant	Av. Flow (g.p.m.)	Aeration Tank		Settling Tank		Raw B.O.D.[3] (lb./day)	Air Supplied[4] (c.f.m.)	
		Cap.[1] (gal.)	Ret. (hr.)	Cap.[2] (gal.)	Ret. (hr.)		Total	Per lb. B.O.D./day
T	1.96	13,500	115	735	6.25	18	21	1.2
S	1.88	8,100	72	735	6.5	16	12	0.8
	2.22	8,100	61	735	5.5	23		0.5
N	1.69	12,600	124	735	7.25	13	12	0.9
F	2.07	4,500	36	735	6	13	12	0.9

[1] Corrected volume, allowing for estimated average depth of mixed liquor in tank.
[2] Excluding volume of flow stabilization zone.
[3] Estimated, based on probable raw B.O.D. load of 4 lb. per 10,000 lb. of milk received.
[4] Based on an empirical figure of 1.5 c.f.m. per suction jet.

TABLE II.—Typical Operating Results [1]

Plant	No. of Samples	Season	Milk Rec'd (1,000 lb.)	Waste Volume (g.p.d.)	B.O.D. (p.p.m.)	Red. from Stand. Loss[2] (%)
T	28	5/7–6/3	45.0	2,820	209	88.5
S	62	1/17–3/18	39.1	2,700	180	88
	22	5/29–6/21	57.8	3,200	116	94
N[3]	22	5/1–5/25	32.2	2,430	31	98
N[4]	22	5/1–5/25	32.2	2,440	215	85
F	23	9/1–9/24	33.4	2,980	28	98

[1] All analytical data on treated waste except where indicated.

[2] Standard loss for these plants, as proposed by the Pennsylvania Assn. of Milk Dealers and accepted by the State Department of Health, is 9 lb. B.O.D. per 10,000 lb. of milk received.

[3] Treated.

[4] Raw.

Influent Weir Tank

Waste leaving the milk plant flows to the combination flow equalization and aeration tank, the main unit of the waste treatment unit. Influent weir tanks for flow measurement and sampling are generally not provided because of cost. The State of Pennsylvania, in cooperation with the Sanitary Engineers Committee of the Pennsylvania Milk Dealers Association, has set up certain standard losses per unit of product. The State is now basing its requirements for B.O.D. reduction on these standard losses, rather than on the actual product losses from the plant. In this way waste saving is encouraged, as the efficient milk plants will have an easier treatment job to do than the inefficient plants. Standard loss figures are applied to the highest annual average production for three consecutive days. This means that the treatment plant must be designed for the maximum period, with the result that there are other periods when the treatment plant may have considerable excess capacity.

Because the required B.O.D. reduction is based on standard losses, it is only necessary to analyze the effluent from the treatment plant in order to satisfy State requirements. The result reported to the State is that indicated in the right-hand column of Table II. This means that there is generally no way of evaluating the performance of the treatment plant *per se*. However, a few plants have been provided with influent weirs for research purposes.

Aerated Equalizing Tank

Inasmuch as the waste load in milk plants is very irregular and does not enter the treatment plant at a constant rate, it generally has been felt that it is advantageous to equalize the flow in an aerated holding tank before it enters the aeration tank.

The authors' experience has been that better over-all air utilization can be obtained by combining the two units and letting the aeration tank balance the waste load over the 24 hr. by a variation in the liquid level. This type of design has the disadvantage that at certain times during the day the oxygen demand becomes very high and there may not be enough air supplied to keep the aeration tank completely aerobic. However, oxidation-reduction potential studies have indicated that the oxidative function of the activated sludge is not seriously affected by short anaerobic periods.

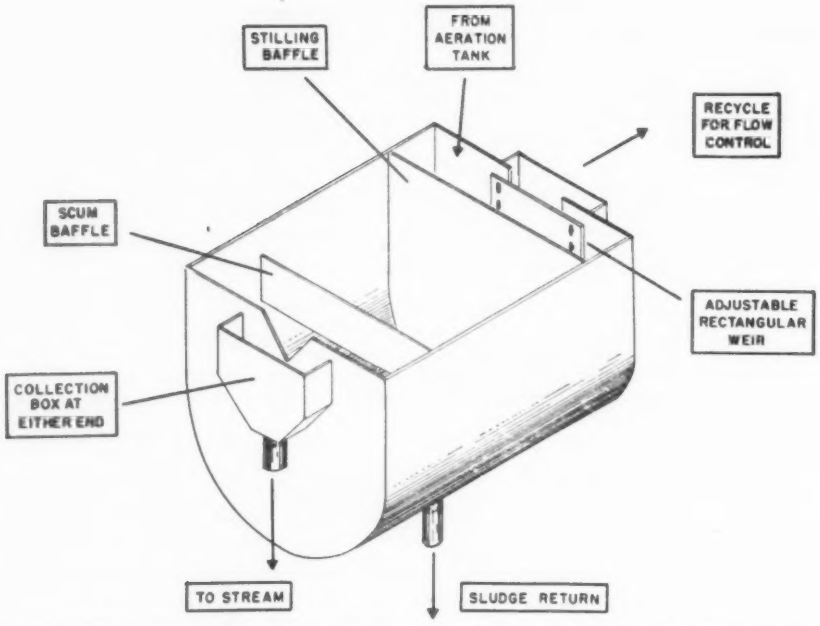

FIGURE 2.—Combined settling, sampling, flow division, and weir tank, with scraper mechanism omitted for clarity.

The air in these small treatment plants generally is supplied from a single source; therefore, the variation in the liquid level in the holding tank is sufficient to induce wide pressure changes on the air diffusers unless a complicated pressure control system is installed. This means that towards the end of the night, when there is relatively little material in the holding tank, a great deal of air is supplied to this tank and the aeration tank gets comparatively little. Consequently, it has been found more effective to combine the two tanks.

Aeration Tank

In some plants aeration tanks have been built underground, whereas in other plants overground steel tanks were used. The choice of tank type depends on what facilities are available or what may be obtained locally at least possible cost. In one plant an old underground septic tank was converted to an aeration tank and a small concrete-block house was built on top of the aeration tank to contain the pump and the combination weir, settling, and flow division tank.

At another location, a second-hand steel tank was purchased at low cost and placed inside a large empty garage on the property. At still another plant, where somewhat larger aeration capacity was needed, the problem was solved by the purchase of three old railroad tank cars which were cut in half, up-ended, and the halves used as aeration tanks. In still another case, the most economical solution to the problem involved the construction of partly underground concrete-block aeration tanks with precast concrete slab covers. Some waste may drain through the sandy soil, but this is not objectionable, as there is no direct discharge of untreated waste to the stream.

Insofar as aeration tank design is concerned, primary interest has been in

the minimum necessary aeration capacity, and any low-cost tank was acceptable. For this reason, some aeration tanks have average retentions of as much as 120 hr. (Table I), even though this is known to be a great deal more than is needed.

The minimum retention time used for the design of aeration tanks has been 30 hr. This period is a little shorter than that recommended by Hoover and Porges (4), who have shown that 36 hr. is necessary for complete oxidation of milk wastes. When the waste is biologically oxidized, it is rapidly converted into cellular protoplasm. The rest of the time is needed for the bacterial cells to digest themselves so as to maintain a more or less constant, or equilibrium, sludge concentration where the amount of sludge built up by the formation of new protoplasm is equal to the amount of sludge destroyed by autoxidation.

Experience has shown that this equilibrium is not particularly difficult to maintain. In more than 1½ years of operation of the previously described waste disposal plants, it has not been necessary to remove excess sludge, because it remains in the system until completely digested.

In the long run, it appears that in small plants the use of aerobic digestion is more economical than anaerobic digestion, because it eliminates the need for an extra tank with associated piping.

Settling, Flow Division, and Weir Tank

The final unit in most of the treatment plants is a small combination settling, sampling, flow division, and weir tank. This tank, made in one standard size, is shown in Figure 2.

The tank is rectangular with a semicylindrical bottom. At the effluent endwall is a 90° V-notch weir; on the influent endwall is an adjustable rectangular weir. Settled sludge is withdrawn through a central discharge pipe in the bottom of the tank with the aid of a mechanical spiral scraper, which moves the sludge from both ends toward the center. This tank has the following functions:

1. Settling—Based on the equalized effluent flow, a retention period of 2 to 7 hr. is provided in the settling portion of the tank. However, since the sludge return rate is larger than the rate of effluent flow, there is little danger of getting anaerobic conditions, even with long retention.

2. Sludge Removal and Return—Sludge solids that settle to the bottom of the tank are moved by the spiral scraper to a central discharge pipe and returned continuously from there to the aeration tank. The liquid level in the settling tank is above that in the aeration tank so that the sludge can be returned by gravity.

When the tanks were originally designed, no scraper was provided. After a month or two of operation, it was found that sludge accumulating on the sides and bottom of the tank became septic after a short time, producing the usual unsatisfactory conditions. This difficulty was eliminated at a small extra cost by the installation of the very simple spiral scraper.

3. Flow Regulation—To get reliable flow control with a minimum number of valves and pipes, the combination of a V-notch and a rectangular weir was used. The adjustable rectangular weir is usually set so that there is an almost constant 24-hr. flow over the V-notch weir at the opposite end of the tank. The flow over the rectangular weir is returned by gravity to the aeration tank.

4. Sampling—Automatic Trebler samplers (5) have been installed near the effluent end of the tank about 1 ft. from the V-notch weir. These samplers are designed to collect samples every 4 min. in direct proportion to the instantaneous flow rate over the weir.

Aeration Methods

Of several methods of aeration investigated, the simplest one employed a recirculating pump and a splash plate. This method worked well where very small amounts of air were required, but in practice it did not supply enough air to provide any margin of safety for the maintenance of aerobic conditions.

A second method relied on Saran-wound diffuser tubes to produce a fine air dispersion. Considerable difficulty has been encountered from the clogging of these tubes, which in some cases has been bad enough so that it was necessary to change tubes for cleaning every day. In one plant it was found possible to keep the tubes clean by the introduction of 1 lb. of excess steam pressure into the air header line. However, when this technique was tried in other plants, it was found that the diffusers clogged more rapidly than they did without the steam.

An important cause of diffuser clogging appears to be rust from the inside of the down pipes. Inasmuch as these plants are located in the country, there are relatively frequent power interruptions. Even if swing diffusers were used to start the aeration tank in service, power failures might still occur, allowing water to back up in the diffusers and down pipes.

TABLE III.—Daily Variations in Oxidation-Reduction Potential [1] and pH of Aeration Tank Mixed Liquor at Three Dairy Waste Treatment Plants

Plant	O-RP (mv.)		pH	
	Range	Mean	Range	Mean
S	+35 to −153	−30	7.30 to 7.40	7.35
N	+200 to +270	+230	7.25 to 7.50	7.35
F	+10 to +210	+110	6.50 to 7.40	6.90

[1] Measured with a platinum-calomel system; not corrected to the hydrogen half-cell.

In general, jets have been found to be more satisfactory than diffuser tubes as aerating devices. These jets are used as air suction and mixing jets, feeding the air-liquid mixture into the aeration tank. In other plants the jets are fed compressed air, in which case the amount of aeration per jet is greatly increased. Jets have been installed in aeration tanks both submerged in the aerating mixture and on the outside of the tank. When the aeration tank is overground, the use of outside jets with valves before and after each jet allows them to be cleaned, when and if they clog, while the tank is in operation. Usually jets do not clog with milk waste except during the early stages of operation when small bits of construction material left in the recirculation lines are later forced into the throats of the jets.

In the four small treatment plants described herein, submerged suction jets are used for aeration. With shallow tanks, these jets will suck air from the atmosphere at the rate of about 1.5 cu. ft. per minute per jet if fed with 12.5 g.p.m. of liquid at 15 p.s.i. If the jets clog, as may be noted by the absence of a boil beyond the end of the jet, they are removed and cleaned.

Thayer (6) has indicated recently that 3 to 4 c.f.m. per pound of B.O.D. per day would be a reasonable design basis for small dairy waste treatment plants. It should be pointed out that this recommendation was made for a treatment plant in which the aeration tank was preceded by an aerated holding tank, which, as previously pointed out, uses a great deal of air. As shown in Table I, the air supplied may be as low as 0.5 c.f.m. per pound of B.O.D. per day. Under these circumstances, it is possible that during the period of peak load the oxygen demand will exceed the rate at which oxygen can be supplied and the oxidation-reduction potential may drop below zero, as shown in Table III. This has not had an ad-

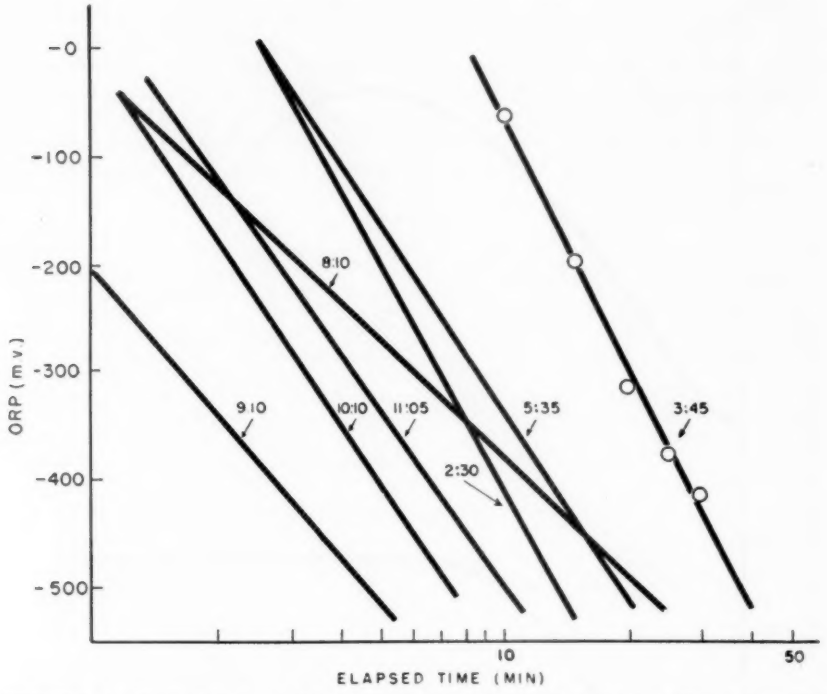

FIGURE 3.—Rate of change of oxidation-reduction potential of mixed liquor from the aeration tank of a small dairy waste treatment plant.

verse effect on the operation of the treatment plant as a whole. As a matter of fact, oxidation-reduction potential studies have indicated that the metabolic activity of the organisms in the aeration tank is not affected appreciably by such drops.

Oxidation-Reduction Studies

Inasmuch as oxidation-reduction potential is an indication of the oxidizing or reducing characteristic of a system, it has been felt that the rate at which microorganisms reduce the potential in a closed biological system can give a good indication of the amount of bacterial activity. Without going too deeply into the theory of the potential and its measurement, a brief discussion may suffice to indicate how such measurements can be useful.

Essentially, the equipment used for field studies on the oxidation-reduction potential changes in mixed liquor consists of a large Erlenmeyer flask stoppered tightly at the top and filled so that all air bubbles are excluded from the flask. In the rubber stopper are mounted a thermometer, a glass electrode, a platinum electrode, and a calomel electrode. A small laboratory stirrer is used to prevent settling. The space between the drive shaft and the rubber stopper is sealed with oil.

In general, when bacteria oxidize food material, the oxidation-reduction potential drops; the more rapidly oxidation takes place, the more rapidly does the potential drop. Figure 3 shows the typical results obtained at one dairy waste treatment plant from samples of mixed liquor taken throughout the day.

If the slope of these curves (the

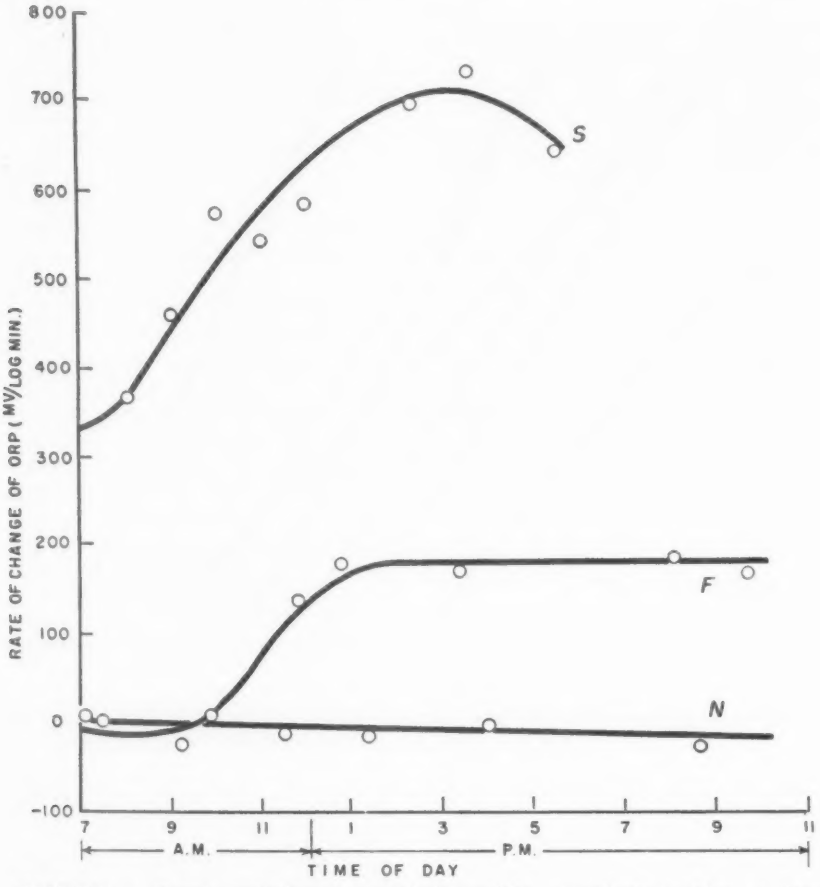

FIGURE 4.—Hourly variations in metabolic activity of activated sludge at three small dairy waste disposal plants, as measured by rate of change of oxidation-reduction potential.

time rate of change of oxidation-reduction potential) is plotted against time, the curves of Figure 4 are obtained. The curves of Figure 4 represent three basically different types of aeration tank operation. Normally, the waste flow first enters the treatment plant sometime around 7 AM and ceases around noon. The lower curve was obtained from the treatment plant in which there was an average retention in the aeration tank of about 120 hr. The curve indicates, as one might expect, a very low level of metabolic activity throughout the entire day.

The upper curve indicates a very high level of bacterial activity, reaching a maximum about 3 PM. This is the plant in which only 0.5 c.f.m. of air is supplied per pound of B.O.D. per day. As indicated by the curve, the fact that the oxidation-reduction potential in the aeration tank at this plant drops below zero does not adversely influence the metabolic rate.

Conclusion

It has been found possible to build dairy waste treatment plants consisting essentially of only an aeration tank and

a small final settling tank. These plants operate satisfactorily with very little maintenance. The air supply to them may be as low as 0.5 c.f.m. per pound of B.O.D. per day. Although the combination of a small air supply and the absence of an aerated holding tank may cause the oxidation-reduction potential in the aeration tank to drop temporarily below zero, the daily operation of the waste disposal units has not been adversely affected and the plants turn out effluents that are entirely within State requirements.

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ENVIRONMENTAL HEALTH CENTER TRAINING COURSES

Twenty-three training courses in various aspects of environmental sanitation will be conducted by the Environmental Health Center of the U. S. Public Health Service at Cincinnati, Ohio, during the period from September 10, 1953, to June 30, 1954. These short courses are given for professional personnel from state and local health departments, water pollution control agencies, the USPHS, other governmental units, educational institutions, and industries cooperating with these agencies in environmental sanitation programs.

The schedule includes advanced training in chemical, bacteriological, biological, and engineering aspects of stream and industrial waste surveys for water pollution control, and short courses dealing with special problems in water and industrial waste analyses, water supplies, sewage disposal, milk and food sanitation, radiological health, and occupational radiation protection.

A bulletin describing the 23 courses and the prerequisites for each is available upon request from the Officer in Charge, Environmental Health Center, U. S. Public Health Service, Cincinnati, Ohio.

RAPID PROCEDURE FOR ESTIMATING ORGANIC MATERIALS IN INDUSTRIAL WASTES

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The presence of high and fluctuating concentrations of chlorides in Lederle Laboratories' industrial wastes made desirable a chemical oxygen consumed determination not subject to interference by chlorides. This objective was attained by combining the alkaline permanganate method of Benson and Hicks (1) with that of Stamm (2).

In addition to non-interference by chlorides, the new method has the advantages that the digestion period is only 10 min. at room temperature, and the only apparatus required consists of glassware usually found in any laboratory equipped for volumetric analysis. Moreover, only one of the five solutions employed need be standardized.

Although the oxygen consumed values in p.p.m. were in general only approximately 60 per cent of the corresponding 5-day B.O.D. values, their precision was unexpectedly good, inasmuch as the coefficients of variation were generally in the neighborhood of 0.01 as compared with published coefficients of variation of 0.006 for oxygen consumed from dichromate determinations under the best conditions (3).

TABLE I.—Oxidation of Alcohols by Alkaline Permanganate at Room Temperature

Alcohol	Oxygen Cons.[1] (% of theor.)
Capryl	19.4
Amyl	17.6
Butyl	19.0
Isopropyl	73.5
Ethyl	37.8
Methyl	97.2

However, compounds having hydrocarbon chains in the molecule were incompletely oxidized, as illustrated by the data for alcohols (Table I). The higher members of the series were commercial products and probably contained enough branched chain isomers to account for the irregularities observed. This is suggested by the relative difference in susceptibilities to oxidation shown by ethyl and isopropyl alcohols.

The variation of susceptibility to oxidation with chemical structure restricts the application of oxygen consumed values, but it seems likely that they will find increasing use in comparing two samples of the same waste that have undergone different treatments, or samples taken before and after treatment.

Reagents

1. Potassium permanganate solution, 0.5N.
2. Potassium permanganate solution, 0.1N (standardized).
3. Sodium hydroxide solution, 30 per cent.
4. Preventive solution. 85 g. $MnSO_4 \cdot 4H_2O$, 225 ml. conc. H_2SO_4, and 175 ml. 85 per cent H_3PO_4 per liter.
5. Mohr's salt solution. 196 g. $Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$ and 150 ml. conc. H_2SO_4 per liter.

Procedure

Into a 500-ml. Erlenmeyer flask pipet 50 ml. of 0.5N permanganate and 25 ml. of sodium hydroxide solution. Mix, add 50 ml. of the correctly

diluted sample, mix thoroughly, and allow to stand at room temperature for exactly 10 min. Add 50 ml. of preventive solution, followed immediately by 50 ml. of ferrous ammonium sulfate solution. After the precipitated hydroxides have redissolved, titrate against 0.1N permanganate to the first permanent pink. The net titration should not exceed 40 ml.

Oxygen consumed, in p.p.m.

$$= \frac{(\text{ml. titration} - \text{blank}) \times 8{,}000 \times \text{normality of } KMnO_4}{\text{ml. of sample}}$$

A blank determination, in which the sample is replaced by 50 ml. of distilled water, must be made in the same manner. If the ferrous ammonium sulfate does not reduce the 0.5N permanganate completely in the blank determination, or if the blank is inconveniently large, the concentration of either solution may be adjusted as convenience dictates, provided the departure from 0.5N is small.

To illustrate the usefulness of the method, catch samples of the influents and effluents of three trickling filters operating on the same waste in parallel were assayed as shown in Table II. Each filter was fed from its own sedimentation tank, and the rate of feed and recirculation was the same for all three, but the effluents from Filters 2 and 3 were mixed before half of the common effluent was returned to each of their respective sedimentation tanks. The samples were centrifuged for 10 min. at 135 *g*'s to separate insoluble matter.

The data (Table II) show excellent agreement between duplicate determinations; the largest difference was 22 p.p.m., or approximately 3 per cent.

Table III indicates the following:

1. The waste received in the morning was weaker than that received in the afternoon. This is shown by the values for each filter, as well as the averages of the three.
2. The filter influents (sedimentation tank effluents) showed increasing strengths in the order Filter 1, Filter 3, and Filter 2. This was true for both morning and afternoon values.
3. The effluents from Filters 1 and 3 were of the same strength and both were weaker than the effluent from Filter 2.
4. The morning effluents were better than those of the afternoon. Table IV shows the following:

TABLE II.—Oxygen Consumed by Permanganate (in P.P.M.) for Duplicate Determinations on Catch Samples Taken April 29, 1952

Sample	Influent, Filter No.			Effluent, Filter No.		
	1	2	3	1	2	3
AM	582	716	658	512	566	514
	584	720	680	504[1]	566	498
PM	726	826	787	610	662	606
	718	816	780	621	666	611

Coefficient of Variation = .011.

[1] Sample lost; value calculated from the remaining data.

TABLE III.—Oxygen Consumed by Permanganate (in P.P.M.)[1]

Sample	Influent, Filter No.				Effluent, Filter No.			
	1	2	3	Av.	1	2	3	Av.
AM	583	718	669	657	508	566	506	527
PM	722	821	784	776	616	664	609	630
Av.	653	770	727	717	562	615	558	579

[1] Averages of duplicate determinations.

TABLE IV.—Oxygen Consumed Reduction Due to a Single Pass Through the Filters

Sample	Reduction (p.p.m.)				Reduction (%)			
	Filter No.				Filter No.			
	1	2	3	Av.	1	2	3	Av.
AM	75	152	163	130	12.9	21.2	24.4	19.5
PM	106	157	175	146	14.7	19.1	22.3	18.7
Av.	91	155	169	138	13.8	20.2	23.4	19.1

1. Filter 1 effected a smaller reduction than Filter 2, which in turn showed a smaller reduction than Filter 3, in spite of its receiving stronger waste. The over-all difference (155 p.p.m. *vs.* 169 p.p.m. for Filters 2 and 3) is highly significant; that is, the chances that it was due to errors in assay are very small, and therefore it may be assumed to be real.

2. The reduction occurring in the morning was less than that occurring in the afternoon. This was to be expected, as the wastes processed in the afternoon were stronger.

3. When the reductions were converted to percentages, it was apparent that with the exception of Filter 1, the weaker (morning) waste showed a higher per cent reduction than the stronger (afternoon) waste, although the reduction in p.p.m. O.C. was the reverse. In connection with the failure of Filter 1 to conform, the fact that its effluents were of the same strength as those of Filter 3 might give rise to the suspicion that these effluents now contained only the more difficultly oxidizable residues from the original waste.

4. Conversion to percentages caused little apparent change in the relative performances of the filters.

In another application at Lederle, samples of effluents from individual buildings were taken at regular intervals throughout the day, and composites were made up for each building. The composite samples were subjected to distillation and the oxygen demand of each distillate was determined. Over a period of time, the normal range of values for the effluent from each building has been established; abnormally high values are now interpreted as indicating leaks, excessive spillage, improper maintenance, or other conditions which should be brought to light and remedied.

The rapidity and convenience of the alkaline permanganate oxidation make it possible to make larger numbers of determinations, and so facilitate the carrying out of experiments of relatively complex design. In plant operation, the rapidity with which the results become available should make the O.C. determination useful in emergencies where decisions must be made promptly.

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PERIODATE OXIDATION OF PEA CANNERY WASTES

By Roy B. Flay *

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It is recognized generally that a faster method for determining the degree of pollution of a community or trade waste is needed. The standard B.O.D. determination takes much too long, and metering wastes into a stream on the basis of the standard B.O.D. does not offer a very good control. The more rapid chemical method herein described offers a partial solution to the problem for one type of waste and gives indication of the point of attack of the bacteria in the first stage of bacterial oxidation.

During a search for supplemental data with which to predict the B.O.D. of the effluents from a pea cannery, it was thought that an analysis for the various constituents in the waste might have an empirical relation to the B.O.D. Total solids, nitrogen (protein), sugars, and sugar-like materials in the wastes were the substances investigated for this relationship.

The wastes in the pea cannery varied widely in the concentration of organic material, with B.O.D. values ranging from 15 p.p.m. in the cooling water to 37,000 p.p.m. in the blancher overflow. Because of this wide variation, the usual total oxidation procedures were not suitable for the work. The higher concentrations could be diluted and oxidized by any one of various methods with fair results, but the oxygen consumed value of very dilute wastes could not be obtained with any degree of accuracy, even by diluting the oxidizing mix. Several of the total oxidation procedures (1) (2) (3) using dichromate, permanganate, ceric salts, peroxides, iodate, and others at various pH's and with various catalysts, have been tried in the laboratory. It was found that the necessary close control of the digestion temperature was difficult above steam-bath temperatures; difficulty was encountered in obtaining a good standardization in some of the viscous phosphoric-sulfuric acid digestion mixtures; and it was found that digestion mixtures less than 0.1N, for dilute wastes, decomposed anomalously on heating and, consequently, gave poor accuracy for determining the O.C. of dilute wastes.

During the 1952 pea canning season, daily samples were taken from various parts of the Green Giant Cannery at Dayton, Wash., and analyzed for B.O.D., periodate O.C., nitrogen, and total solids. In all, 70 samples were taken. The results are summarized in Figures 1, 2, and 3.

The total solids determinations were made by evaporating 250 ml. of the waste to dryness on the steam bath, except for the highest concentration of wastes (over 10,000 p.p.m.), which were determined by lyophilizing a 100-ml. sample. The steeper slope at the high end of the curve (Figure 1) is probably due to the difference in procedure, but the curve is still usable for an empirical approximation of the B.O.D. The total solids determination has several disadvantages for routine estimation of the B.O.D. in that evaporation is a slow process; some decomposition of the material results after most of the water is evaporated; and dirt, leaves, and pods left by mechanical washing give a considerably different B.O.D. *vs.* solids ratio from the cooking process where the waste water contains high percentages of dissolved material, which is more easily digested by bacteria.

The nitrogen (protein) determina-

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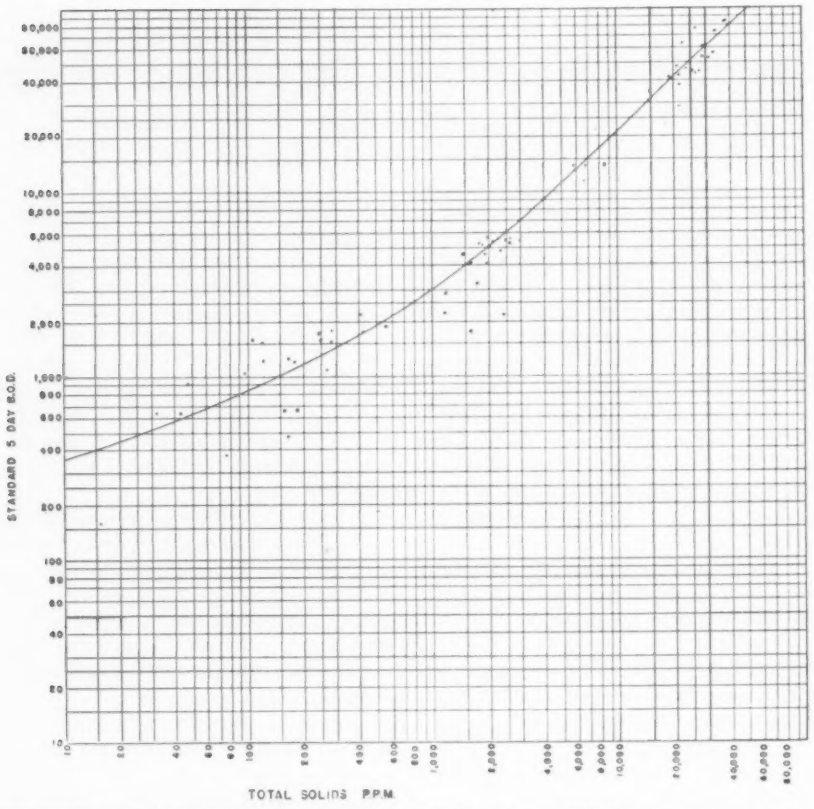
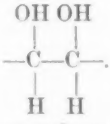


FIGURE 1.—Relationship of standard 5-day B.O.D. to total solids for pea cannery wastes.

tion on the various pea cannery wastes gives a much better correlation with the B.O.D., but is restricted to the higher concentrations because of the obvious difficulty of obtaining accurate values at low concentrations. The nitrogen determinations were made by the standard A.O.A.C. methods (4) on waste containing at least 70 to 80 p.p.m. nitrogen, which represents B.O.D. values greater than 1,000 p.p.m. (Figure 2). This protein-B.O.D. relationship is very good and indicates good possibilities for routine control of cannery effluent.

The periodate oxidation method gave the best correlation of all (Figure 3). Periodate has the property of being a specific reagent for oxidizing certain types of chemical bonds (5)—that is,



. These bonds are especially prevalent in sugar-like material, such as that leached out of peas in the various washing and cooking operations. Therefore, oxidation of the pea waste by periodate should give a measure of the sugar content or, conversely, the oxygen necessary to oxidize the sugar-like material in the waste. In pea cannery effluent, assuming that any other reaction is negligible, some of the periodate cleaves the sugars and is reduced to KIO_3. This reduction should be equivalent to the oxygen demand of a given sample.

The excess periodate (that is, the

periodate not reduced in the system) liberates free iodine from KI in neutral solution, reacting according to the quantitative reaction

$$KIO_4 + 2KI + H_2O \xrightarrow[NaHCO_3]{} I_2 + KIO_3 + 2KOH$$

Reagents

1. Periodate oxidizing reagent is prepared by dissolving 2.303 g. potassium periodate in 1,500 ml. of water, heating on steam bath if necessary to obtain complete solution. Then dissolve 10 g. of anhydrous $NaHCO_3$ in the solution, cool and make up to 2 l. This solution is 0.01N in respect to the reaction $KIO_4 \rightarrow KIO_3$.

2. Arsenic trioxide reagent 0.01N is prepared by dissolving 0.9893g. AS_2O_3 in 1,500 ml. of water containing about 1 g. NaOH. After solution, add 50 g. $NaHCO_3$ and make up to 2 l.

3. Granular potassium iodide is used dry as a source of iodide for reduction of the periodate not reduced in the system, because of the tendency to decompose in solution.

4. Starch indicator solution.

5. Sodium bicarbonate, anhydrous AR.

Procedure

Dilute the sample with distilled water until the solution has an oxygen demand of approximately 3 to 4 p.p.m. This dilution is determined by trial and error, using the periodate reagent. The

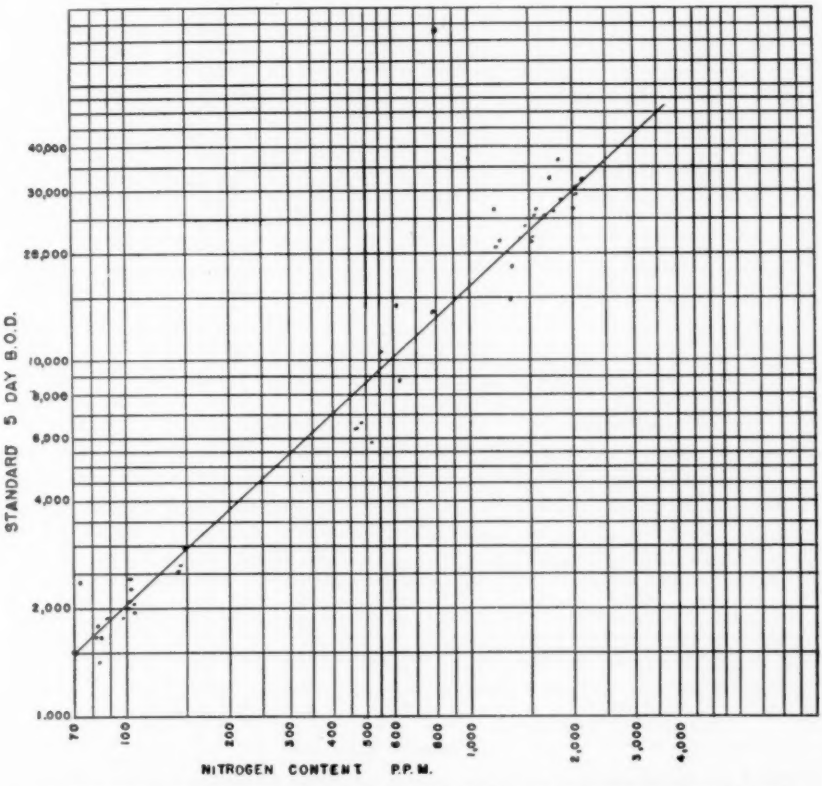


FIGURE 2.—Relationship of standard 5-day B.O.D. to nitrogen content for pea cannery wastes.

dilution in usual circumstances will be the same for all other samples from the same source. Then pour 200 ml. of this diluted sample into a 400-ml. beaker containing approximately 5 g. of $NaHCO_3$ and pipet in 20 ml. 0.01N KIO_4 reagent. Place on steam bath for 2 hr. with a blank made up in the same manner using 200 ml. of distilled water in place of sample. Remove from steam bath and cool. After cooling, add approximately 1 g. of granular KI to sample, titrate to pale straw color with 0.01N A_2O_3, then add starch indicator and titrate to colorless end point. Proceed in the same manner with the blank.

O.C. = Oxygen consumed by periodate.
B = ml. 0.01N As_2O_3 to titrate blank.
S = ml. 0.01N As_2O_3 to titrate sample.
F = Dilution factor (that is, 10,000 for 1–10,000 dilution).
V = ml. diluted sample titrated.

$$O.C. = (B–S) \times \frac{F}{V} \times 8 \times 1{,}000 \times 0.01$$

To check the relation of this periodate oxidation with the standard 5-day B.O.D., samples were incubated using the standard B.O.D. technique (1) and then oxidized by this periodate procedure after 0, 1, 2, 3, 4, and 5 days of incubation. It was found that after the 5-day period only

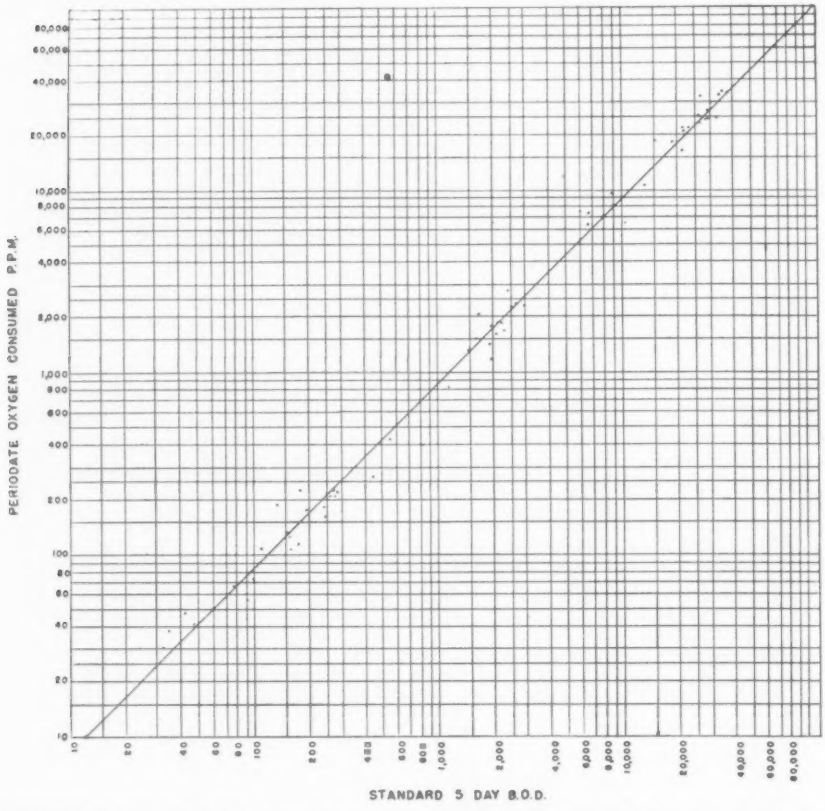


FIGURE 3.—Relationship of periodate oxygen consumed to standard 5-day B.O.D. for pea cannery wastes.

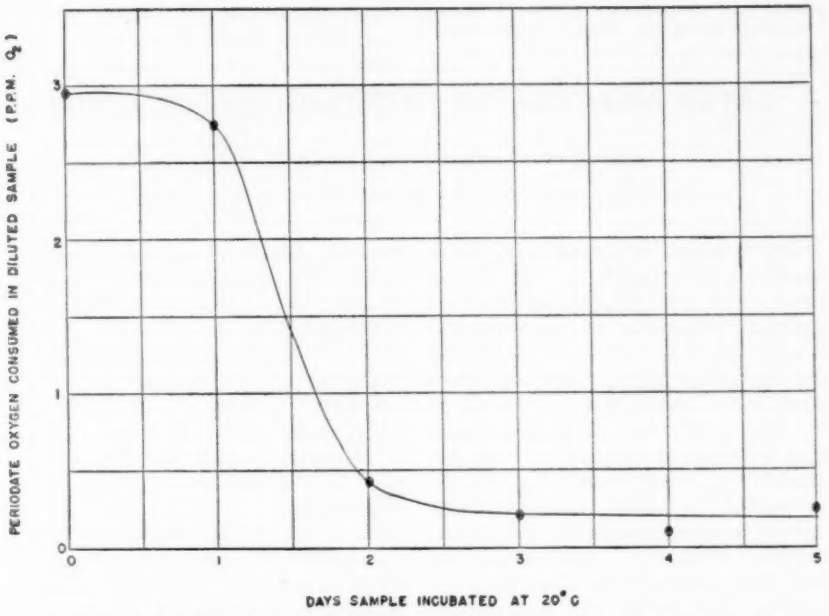


FIGURE 4.—Relationship of periodate oxygen consumed to incubation time of pea cannery wastes.

a trace of sugar or material oxidizable with neutral periodate was left (Figure 4). This result, coupled with the nearly equal relationship of the B.O.D. and the O.C. from periodate, indicates that the first stage of bacterial oxidation in the digestion of pea waste in a B.O.D. test is centered on certain bonds peculiar to sugars or sugar-like material.

Periodate oxidation of the sugar-like materials in pea waste gives a very excellent correlation to the 5-day B.O.D. The oxygen consumed value from periodate and the B.O.D. gives nearly a 1 to 1 relationship. This, coupled with the fact that after 5-day incubation only a trace of sugar-like material is left, indicates that in pea cannery effluent the 5-day B.O.D. represents almost entirely the oxygen uptake due to the bacterial oxidation of the sugars. It is thought that this method would work equally well on other industrial wastes containing sugar or sugar-like materials in some proportion.

Acknowledgments

The author wishes to acknowledge the assistance of Steven Freer and William H. Harris in the laboratory, and of Gene Leete and Jack Dixon for technical advice and editorial criticism, respectively.

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RAPID ANALYSIS OF PACKINGHOUSE WASTES

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Over a period of a great many years much research has been done to develop rapid and practical methods of analysis adaptable to packinghouse sewage. It has long been recognized that the 5-day B.O.D. analysis leaves much to be desired, largely because of the chance of error introduced when high dilutions are required. It is also desirable to obtain results as rapidly as possible in order that immediate corrective measures can be taken when trouble develops. Another major analytical problem arises from the presence of free grease in the samples. There are many methods available for analyzing grease content; however, most of these methods are quite elaborate and time consuming. It has been the authors' purpose to develop and adapt suggested methods to the peculiarities of packinghouse sewage. This paper deals primarily with evaluation of some methods that have appeared to be effective from the standpoints of speed and reproducibility.

Oxygen Demand

The first steps taken in the direction of rapid determination of oxygen demand involved a comparison of results obtained from the 5-day B.O.D. analysis as outlined in "Standard Methods" (1) with results of a chemical oxygen consumed method proposed by Johnson, Tsuchiya, and Halvorson (2). This chemical method utilizes the oxidizing action of iodic acid formed when sulfuric acid is added to potassium iodate. The iodic acid oxidizes all oxidizable substances except amino and ammonia nitrogen. A Kjeldahl nitrogen determination is thus necessary to calculate the demand caused by the presence of nitrogen-bearing compounds. Total demand is determined by measuring the residual iodate iodometrically, calculating the oxygen demand from the consumption of iodate, and adding the calculated theoretical demand from nitrogenous materials. This method is reasonably rapid, requiring about 4 to 6 hr. for completion. Some of the disadvantages of the method are the strict control of temperature necessary, quantitative transfer of materials, and steam distillation to remove free iodine released in the oxidation reaction. Results are reproducible only when strict attention is given to good quantitative analytical technique.

Results of the comparison of 5-day B.O.D. with this method, commonly referred to as the iodic acid method, indicate that for packinghouse sewage a valid relationship exists between biochemical and chemical oxidation. Halvorson (3) has stated that 60 per cent of the iodic acid oxygen consumed value should be equivalent to 5-day B.O.D. values on packinghouse sewage. This value has been found to be correct. It is understood that the metabolism of sewage organisms varies greatly. For this reason it is obvious that a different relationship could exist for another source of sewage. Table I shows the comparison between 5-day B.O.D. analyses and 60 per cent of iodic acid oxygen consumed values on duplicate samples of packinghouse sewage.

More recent work by Moore, Kroner, and Ruchhoft (4) indicates that chromate oxidation may give more reliable results on industrial wastes, particularly when silver sulfate is used as a

catalyst. Since the reflux chromate method of chemical oxidation offers several advantages in ease of technique and less necessity for control of temperature, a series of determinations was run on duplicate samples of packinghouse sewage to determine if the results would be significantly different from those found by the iodic acid oxidation method.

Table II shows that in each case higher oxygen consumed values are obtained using the reflux chromate method than when the iodic acid method is used. It has been established by experiment that 51.5 per cent of the chromate oxidation value is equivalent to 60 per cent of the iodic acid oxidation value on this particular sewage.

The theory has been advanced that, since packinghouse wastes are composed almost exclusively of nitrogen- and grease-bearing materials, it should be possible to determine the oxidation values for nitrogen and grease and by calculation arrive at a satisfactory oxygen demand value for the entire waste from the analyses for nitrogen and grease alone. Although it is true that some carbohydrates are present, the quantities found in this sewage are so small that the oxidation value caused by their presence would account for not more than 1 per cent of the total.

In collaboration with Halvorson (3) a theoretical factor for 60 per cent of the oxidation value of nitrogen was calculated to be 4.25. By experimentation in the laboratory a factor for 60 per cent of the oxidation value of grease was determined to be 2.5. Multiplication of the nitrogen and grease concentration found in the waste by the factors of 4.25 and 2.5, respectively, gives a remarkably reliable value for 60 per cent of the oxygen demand of the total waste. Table III shows a comparison of values found by the iodic acid method for oxygen consumed and those calculated from analyses for nitrogen and grease on the same sample. These values indicate that an oxygen

TABLE I.—Comparison of 5-Day B.O.D. and 60 Per Cent of Chemical Oxygen Consumed (by Iodic Acid Method)[1]

B.O.D. (p.p.m.)	Oxygen Cons. (p.p.m.)	B.O.D. (p.p.m.)	Oxygen Cons. (p.p.m.)
7,863	7,608	408	408
2,407	2,325	380	365
1,367	1,142	322	399
1,165	842	273	311
1,020	922	245	221
983	1,297	238	270
896	656	236	303
845	726	234	284
748	520	220	187
626	439	216	200
609	432	198	101
520	566	170	191
493	540	165	98
493	434	159	134
487	394	151	244
483	477	94	113
470	360	40	126
432	398	40	114

[1] Data selected from routine analyses of packinghouse waste to cover a wide range of strengths.

TABLE II.—Oxygen Consumed; Comparison of Iodic Acid *vs.* Reflux Chromate Methods[1]

Date	Oxygen Cons. (p.p.m.)	
	Iodic Acid	Reflux Chromate
12/29/52	2,650	2,769
12/30/52	1,201	1,300
12/31/52	1,015	1,025
1/ 2/53	1,378	1,667
1/ 5/53	1,393	1,563
1/ 7/53	1,217	1,425
1/ 8/53	1,446	1,683
1/ 9/53	1,243	1,385
1/12/53	1,041	1,218
1/14/53	1,120	1,231
1/15/53	1,524	1,678
1/20/53	1,411	1,760
1/21/53	1,655	1,791
1/22/53	1,445	1,924
1/26/53	1,119	1,294
1/27/53	1,025	1,254
1/28/53	1,170	1,279
1/29/53	1,281	1,767
1/30/53	1,026	1,295
2/ 2/53	1,030	1,380
2/ 3/53	1,140	1,396
2/ 6/53	1,478	2,025

[1] Data obtained from routine analyses of packinghouse sewage for one month.

TABLE III.—Oxygen Consumed; Comparison of Iodic Acid *vs.* Calculation from Nitrogen and Grease Analyses[1]

Iodic Acid (p.p.m.)	Calculated (p.p.m.)
2,650	3,770
1,201	1,212
1,015	923
1,378	1,428
1,393	1,170
1,217	1,270
1,446	1,075
1,243	1,042
1,041	945
1,120	960
1,524	1,282
1,411	1,300
1,655	1,792
1,445	1,829
1,119	1,268
1,025	1,801
1,170	1,250
1,281	1,351
1,026	1,298
1,030	945
1,140	984

[1] Typical data selected from routine analyses of packinghouse sewage.

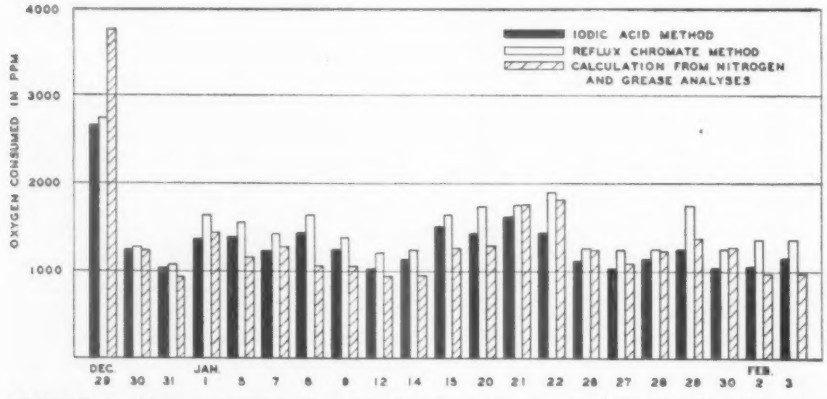
demand figure can be calculated with reasonable accuracy when nitrogen and grease analyses are available.

Figure 1 shows the relative oxygen demand values on packinghouse sewage obtained by each of the three methods discussed. It is evident that each method gives data sufficiently accurate for plant control and most other purposes. Selection of one of these methods for routine use is dependent, therefore, mainly on the degree of precision normally required and the amount of time available for analyses. In most cases it is probable that the reflux chromate method offers the greatest advantages in ease of handling, economy of time, and general reliability.

Grease Analysis

Standard packinghouse practices make it almost impossible to completely eliminate the loss of some grease-bearing materials to sewers. It is important, therefore, to have rapid analytical methods available in order to supply data necessary for proper control of grease recovery equipment at all times.

Many methods of grease analysis are completely useless for purposes of plant control because of the complicated and time-consuming techniques involved. Other more rapid methods are unsatisfactory because of the unreliability of results. It is understood that sampling of wastes high in grease content is a difficult problem. After proper sampling has been accomplished, however, it is possible to obtain reproducible analytical data on the sample without resorting to involved techniques.


4000
3000
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OXYGEN CONSUMED IN PPM
IODIC ACID METHOD
REFLUX CHROMATE METHOD
CALCULATION FROM NITROGEN AND GREASE ANALYSES
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FIGURE 1.—Oxygen demand of packinghouse wastes—comparison of iodic acid, reflux chromate, and calculation from nitrogen and grease analyses.

The method of analysis for grease proposed by Theroux, Eldridge, and Mallmann (5) has been used with minor modifications in this laboratory to obtain very satisfactory results. The modifications of this method consist of removing the dried grease-bearing solids from the evaporating dish to a Soxhlett thimble, wiping the evaporating dish clean with filter paper moistened with distilled water, and adding the paper to the thimble. The evaporating dish, thimble, and contents are then dried overnight in a 105° C. oven. The evaporating dish is then rinsed twice with petroleum ether, the thimble is inserted in an extractor, and the rinsings are poured into the Soxhlett thimble. The thimble and contents are then extracted in the normal manner for 4 hr. The petroleum ether is then evaporated, and the receiving flask is dried 30 min. in a 105° C. oven and then weighed back after cooling in a desiccator.

TABLE IV.—Comparison of Grease Analyses on Packinghouse Sewage by Standard Method (1) and Theroux Method (5)

Sample	Stand. Method (p.p.m.)		Theroux Method (p.p.m.)	
	Duplicates	Average	Duplicates	Average
1	177		166	
	153	165	243	205
2	113		128	
	118	116	128	128

A comparison of the results of analyses made according to "Standard Methods" (6) and those of Theroux, Eldridge, and Mallmann (5) is shown in Table IV. In each case it is indicated that the Theroux method is more effective in extracting grease. Use of the modified Theroux method on packinghouse sewage containing varying amounts of grease has demonstrated that the method gives reproducible results even though grease quantities in the sample taken may be large or small.

TABLE V.—Agreement between Grease Analyses on Duplicate Samples by the Modified Theroux Method[1]

Sample (p.p.m.)		Av. (p.p.m.)
1	2	
556	538	547
459	413	436
311	334	323
221	285	253
200	194	197
131	128	130
94	104	99
93	94	94
84	93	88
27	32	30

[1] Typical data selected from routine analyses on packinghouse sewage to cover a wide range of grease contents.

Some typical results are shown in Table V.

Another, more rapid method of analysis for grease has been proposed by Smith and Sanderson (7). This method utilizes the principles of acidification and vacuum filtration through a bed of high-flow "filter-cel" to accomplish a rapid removal of grease from the sewage. A slightly modified version of this method has been used on packinghouse wastes with excellent results. The modifications consist of standardization of sample volume at 250 ml.; evaporation of the petroleum ether after extraction at atmospheric pressure rather than under vacuum; and substitution of variable-heat hot plates for water baths for control of temperature.

TABLE VI.—Comparison of Theroux and Smith–Sanderson Methods of Grease Analysis on Packinghouse Sewage

Sample	Theroux Method (p.p.m.)		Smith-Sanderson Method (p.p.m.)	
	Duplicates	Average	Duplicates	Average
1	102–98	100	107–118	113
2	160–173	167	163–197	180
3	161–144	152	104–141	123

A comparison of results of analyses on duplicates from samples of packinghouse sewage by the modified Theroux method and the modified Smith-Sanderson method is shown in Table VI, which indicates that these two methods are quite comparable on the basis of total quantity of grease extracted and reproducibility. In view of the data on hand, the Smith-Sanderson grease method appears to be one of the most satisfactory rapid procedures yet developed for use on packinghouse sewage.

Summary and Discussion

Data sufficiently reliable for good plant control and for estimating the probable effect of discharged wastes on the receiving stream can be obtained the same day the sample is taken. Entirely satisfactory results can be had on a routine basis using the rapid methods evaluated in this paper.

Data from the Kjeldahl nitrogen analysis and the Smith-Sanderson grease analysis will give a reliable check on nitrogen and grease losses from the plant. These same data can be used to calculate oxygen demand. Use of these data (which can easily be confirmed by the reflux chromate oxygen consumed analysis) will give the basis for a constant estimate of the probable effect of the sewage on the oxygen resources of the receiving stream. All of this information will be available rapidly enough to permit immediate corrective action whenever trouble develops.

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Stream Pollution

POLLUTION STUDY OF THE RED CLAY CREEK DRAINAGE BASIN

I. Estimation of Stream Flow Time and Self-Purification

By A. Joel Kaplovsky, Herman Mandel, Harry F. Camper, and James D. Murphy

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The findings of a comprehensive study of existing pollution and stream self-purification within the Red Clay Creek drainage basin in the State of Delaware are presented in a series of three papers covering (a) measurement of stream self-purification as determined by physical and chemical means, (b) application of a biological measure to determine existing stream conditions, and (c) a chemical coagulation study of a fiber mill waste discharge.

Basin Description

Red Clay Creek is probably one of Delaware's most picturesque streams. It is formed by the junction of two tributaries—the East and West Branches—in the meadows around Kennett Square, Pa., and winds it way through farming, residential, and industrial areas. The stream is approximately 20 mi. long and flows due south for 10 mi. in Pennsylvania. The Red Clay enters Delaware at a point approximately 1 mi. northwest of Yorklyn, Del. (see Figure 1), and flows south through rolling fields and wooded areas for 7½ mi. to its confluence with White Clay Creek. It is characterized by numerous spillways and flashing rapids. Together, Red Clay Creek and White Clay Creek form a tributary of the Christina River, entering the latter at a point approximately 2 mi. southwest of Newport.

The stream bed is very rocky as is most of the surrounding terrain. The rapid change in stream elevation is the contributing factor to its flashiness. A drop in elevation of 178 ft. constitutes an average slope of approximately 1 ft. for each 300 ft.

The Red Clay Creek drainage basin constitutes a small drainage area of only 47 sq. mi., of which approximately 27 sq. mi. are in Delaware. The major source of pollution entering the Red Clay originates at Yorklyn, Del., from two fiber mills. Approximately 6 mi. downstream additional pollution enters the creek from a chemical experiment station located at Faulkland. The lower reach of the Red Clay receives industrial and municipal discharges in the Marshallton-Stanton Area. Prior to entering Delaware, various types of pollution, such as mushroom, slaughterhouse, and fiber mill wastes, originate in the Kennett Square area in Pennsylvania. The municipal waste discharges from Kennett Square receive secondary treatment before reaching Red Clay Creek.

The compactness of the Red Clay drainage area and the concentrated sources of pollution afforded an excellent opportunity to measure the degree of self-purification of this body of water.

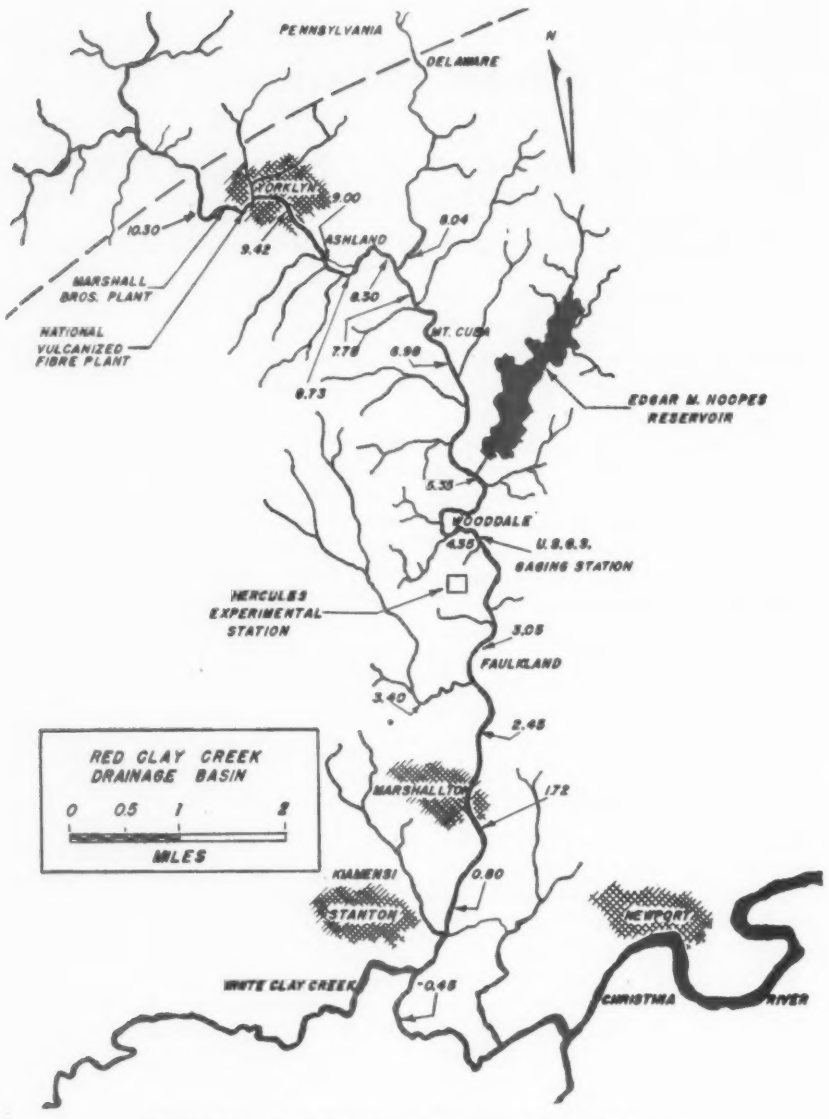

FIGURE 1.—Red Clay Creek drainage basin in Delaware.

Methods

Flow measurements were made of the main stream, its tributaries, and the wastes discharged to the stream in Delaware. Analyses, such as dissolved oxygen and temperature measurements, were also made in the field. Other analyses, as indicated below, were carried out in the laboratory. Stream flow measurements were made with a "pigmy" stream flow meter; additional flow measurements were obtained

from the U. S. Geological Survey gaging station located at Wooddale, Del. All sampling stations are indicated in Figure 1 as miles above the confluence of Red Clay Creek and White Clay Creek. Samples taken within this drainage basin were returned to the laboratory immediately and analyzed. The laboratory analyses were performed according to Standard Methods (3) and consisted of the following:

1. pH.
2. B.O.D. (5-day at 20° C.)
3. Suspended solids.
4. Color.
5. Coliform group (Indicated Number).
6. Alkalinity.
7. Acidity.
8. Dissolved oxygen.
9. Carbon dioxide.

The technique of Churchill (1) was used in addition to the "Standard Method" color measurement. The two procedures are comparable in that they both employ potassium chloroplatinate standard, with the exception that the former does not contain cobalt. The important difference between the two techniques is that the Churchill procedure utilizes an electrophotometer to eliminate human errors in making color comparisons. It is to be noted that each of the above methods has a common defect. Samples which have a different hue from that of the standard may conceivably make a direct comparison difficult if not impossible. Fortunately, in the case of the fiber mill waste color measurements, this inherent difficulty was not encountered, as the waste had a wavelength of 575 $m\mu$.; that is, the hue was similar to the yellow-brown of the standard solution.

Experimental Results

Measurement of Stream Flow Time

The ability of every moving body of water to recover from the effect of pollution is of considerable importance in estimating the load a stream can absorb without ill effects. To estimate this ability of self-purification, the following need be known: the time required for a pollutant to travel from its source to a predesignated point downstream, the total pollutional load discharged, and the residual concentration of pollution at the downstream location.

Stream flow time from the Yorklyn mills (station 9.65) to station 2.45 (see Figure 1) as determined by measuring the velocity at numerous intermediate sampling stations totaled 7 hr. The over-all distance approximated 7.2 stream miles. It was also observed that when the fiber plants were producing colored paper, the time of flow, based on color movement, within the stream was considerably greater (approximately 16.4 hr. to travel the same 7.2 mi.) This obvious discrepancy was attributed to detention received behind the numerous impoundment areas below the waste discharge.

Batch discharge of the strong blowdown waste from the fiber mills, in conjunction with the relatively low volume of flow within the creek, presented an ideal situation for the measurement of stream flow time within this particular body of water. The complicating factors were that the batch blowdown discharges were numerous and occurred at ½- to 1-hr. intervals between each discharge. Often there was overlapping of blowdown discharges.

Time of flow was directly related to the movement of the concentrated discharges, and these movements were followed by utilizing as position indicators the changes in stream alkalinity after various periods of stream flow time. A complete series of samples, including each of the sampling stations designated on Figure 2, could be gathered within 1 hr.

A triple-run series of alkalinity position indicator measurements to determine stream flow movement was made on May 1, 1952. In addition to the alkalinity analyses, color measurements

were recorded. The results (Figure 2) indicate that either the alkalinity or the relative color measurements can be satisfactorily used to determine the time or the movement of stream flow in Red Clay Creek. The second of this triple-run series indicated the position of the initial blowdown discharge to be at station 6.98 after 12 hr. During a previous study (2) a total of 13.5 hr. was required to reach station 6.98. The difference was attributed to increased volume of stream flow. The total flow at the Wooddale U.S.G.S. gaging station during this triple-run series was 194 c.f.s., as compared to 131 c.f.s. during the previous observations. Apparently, the volume of flow also affects the time of flow and must be taken into consideration.

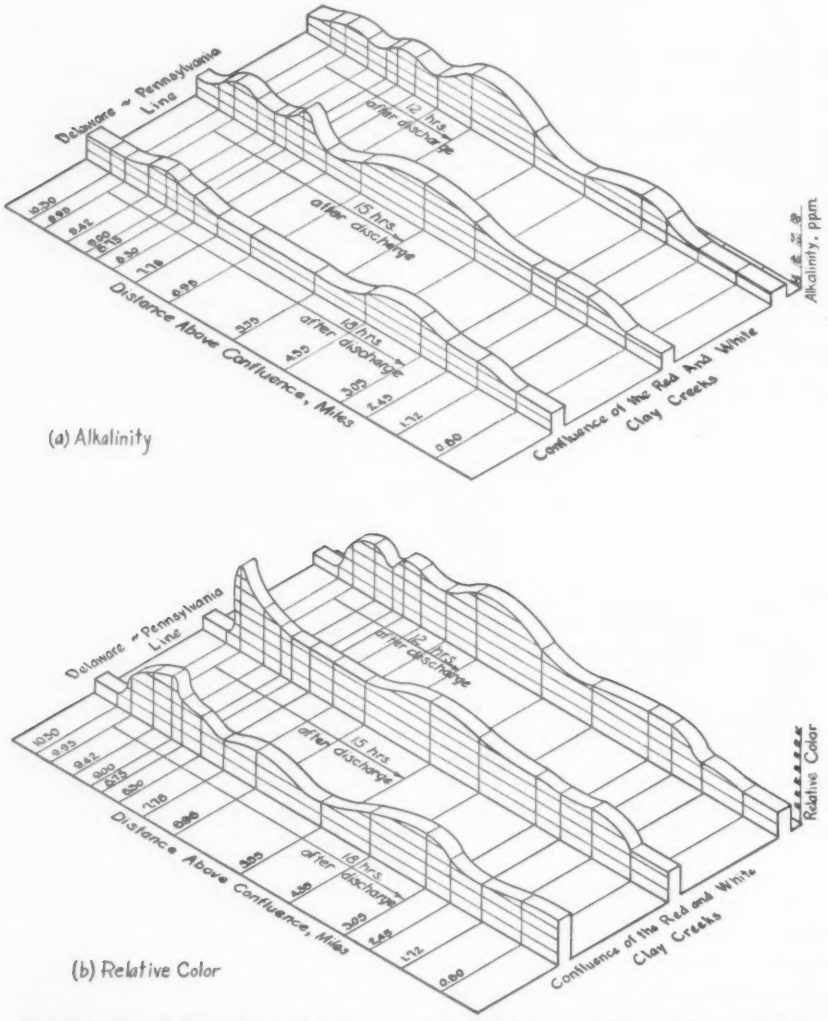

FIGURE 2.—Time of flow of Red Clay Creek, based on concentrated fiber mill blowdown waste movement indicated by periodic measurement of stream alkalinity (a) or relative color (b).

By observing the blowdown discharge movements within the stream, it was concluded that the average time required to reach the Wooddale gaging station (station 4.35) was approximately 15 hr. when the stream flow was 194 to 200 c.f.s.; and, when the stream flow was 130 c.f.s., the total time of flow would increase from 1 to 1.5 hr.

Waste Stabilization

To study the ability of Red Clay Creek to purify pollution entering its waters, an upstream source of pollution had to be determined and measured; and, after a designated period of retention within the stream, the downstream residual pollution had to be measured. The degree of dilution from tributaries entering between these two designated sampling points was previously ascertained.

A strong source of pollution (fiber mills at Yorklyn) afforded a good subject, and the residual pollution at the downstream Wooddale U.S.G.S. gaging station was measured after the proper interval of stream flow time. It may be noted that no pollution entered the stream between the fiber mill discharge and the designated downstream sampling station.

It was observed that the measurement of the waste discharge load received from the fiber plants at Yorklyn and the measurement of the resultant residual pollution load at the downstream station 4.35 could best be determined during the periods of concentrated waste discharges—namely, blowdown. During the periods of blowdown the resultant waste concentration in the stream below the plant and also the concentration after reaching station 4.35 were of sufficient magnitude to insure reliable observations of the waste discharge movements.

On June 11, 1952, an ideal opportunity for waste discharge measurement afforded itself at each of the fiber mill plants. The National plant anticipated an extra heavy blowdown consisting of 30,000 lb. at 2:00 AM with a second discharge of 10,000 lb. at 3:30 AM and a final discharge of 10,000 lb. at 4:30 AM; consequently, these concentrated loads were so spaced as to not complicate the measurements made below (station 9.65) the National plant. A single blowdown discharge at 4:00 AM from the Marshall Bros. plant would not reach station 9.65 in time to interfere with the measurement of National waste discharges.

Samples were gathered from the predetermined locations at 10-min. intervals throughout the sampling period and composited hourly. A total composite also was made of each of the hourly composites.

From the various analyses made, it was noted that the blowdown discharge did emphasize its presence by a very marked increase in waste concentration both at station 9.65 and eventually, to a lesser degree, at station 4.35. The total sampling time at station 9.65 was 3.5 hr., whereas the downstream sampling period required 6.5 hr. to collect the entire series of blowdown discharges. This increased sampling period at station 4.35 can be attributed to the fact that the blowdown discharge lags in the stream as a result of nonuniform stream flow.

The total composite of the waste discharge during the blowdown period received by the stream, as measured at station 9.65, had the following composition: alkalinity 80 p.p.m., B.O.D. 50 p.p.m., suspended solids 62 p.p.m., and a relative color of 225.

Prior to blowdown discharge, samples were gathered from the stream at each station and analyzed. These measurements constituted the pollution load within the stream attributable to washer and white water waste discharges only. The baseline composition at station 9.65 was as follows: alkalinity 43.3 p.p.m., B.O.D. 10.8 p.p.m., suspended solids 37.3 p.p.m., and a relative color of 48.

The blowdown reached the downstream location at station 4.35 after approximately 14.5 hr. of stream flow

TABLE I.—Estimation of Self-Purification in Red Clay Creek between Station 9.65 and Station 4.35 on June 11, 1952

Item	Initial Pollution, Sta. 9.65	Residual Pollution, Sta. 4.35
Flow (c.f.s.)	93.6	117
Total B.O.D. load to stream during blow-down period (lb.)[1]	3,660	1,466
Baseline load to stream, excluding blow-down during sampling period (lb.)[2]	792	401
Baseline load in stream (lb./hr.)	226	62
B.O.D. load attributable to blow-down discharges (lb.)	2,868	1,065
Baseline suspended solids in stream (lb./hr.)	773	692
Stream self-purification[3] of blow-down discharges (%)	—	63.0
Stream self-purification[3] during baseline discharges (%)	—	72.8
Suspended solids reduction in stream (%)	—	10.0
Color reduction in stream (%)	—	71.6

[1] These calculations include the entire blow-down discharge load from the National plant plus the load from the washer and paper machine operations of both the National and Marshall Bros. plants during the sampling period.

[2] Baseline load constitutes the stream load attributable to washer and paper machine discharges during the sampling period.

[3] Based on B.O.D.

time, but sampling was started after 12 hr. to insure total blowdown load recovery. This total composite had the following composition: alkalinity 56 p.p.m., B.O.D. 8.6 p.p.m., suspended solids 39 p.p.m., and a relative color of 85.

During the sampling period at the downstream location, the base line was observed to have the following average composition: alkalinity 46.7 p.p.m., B.O.D. 2.35 p.p.m., suspended solids 26.7 p.p.m., and a relative color of 45.

Based upon these observations, an estimation of self-purification within a distance of 5.3 stream miles and 14.5 hr. of stream flow time was made (Table I).

The total B.O.D. load entering the stream during the blowdown period of 3.5 hr. as measured at station 9.65 was equal to 3,660 lb., whereas the downstream residual total B.O.D. load was 1,466 lb. During each of the periods of sampling, the base line in the stream, which can be attributed directly to washer and paper machine discharges, was 792 lb. at station 9.65 and 401 lb. at station 4.35. Consequently, the B.O.D. load directly attributable to blowdown discharges received upstream amounted to 2,868 lb., whereas the residual pollution downstream attributable to these cooker discharges amounted to 1,065 lb. Stream self-purification, as indicated by the B.O.D. measurements of blowdown discharges, was, therefore, 63 per cent. A relatively good correlation with this estimation of stream self-purification can be made if the baseline B.O.D. load up and downstream are compared. The latter indicates self-purification to be as much as 72 per cent. If relative color changes were considered as a basis for self-purification measurements, the purification would be 71.6 per cent.

Suspended solids reaching the stream due to washing and paper machine operation amounted to 773 lb. per hour as measured in the stream at station 9.65. A careful estimate of the suspended solids concentration at station 4.35 downstream totaled 692 lb. per hour. These suspended solids measurements indicate a reduction of only 10 per cent, which can be considered low. Actually, the shallow water depth behind the impoundment areas and the flashy nature of the stream flow would not be conducive to appreciable sedimentation.

A close study of the changes in dissolved oxygen content of the stream at stations 10.30, 9.65, and 4.35 taken during June 11, 1952, has proven most illuminating. At station 9.65, immediately below the plant, during a blowdown period of sampling the dissolved oxygen content averaged 5.0 p.p.m., with a minimum of 2.3 p.p.m. and a maximum of 6.9 p.p.m. The average,

TABLE II.—Analyses of Water Upstream from Yorklyn (Station 10.30)[1]

Analysis	Sample Designation					
	1	2	3	4	5	6
Time	1:00 AM	5:00 AM	9:00 AM	1:00 PM	5:00 PM	9:30 PM
Temp. (° C.)	20.5	20.0	19.5	19.5	19.5	20.0
D.O. (p.p.m.)	6.8	6.8	8.4	10.8	10.5	8.2
E. coli (M.P.N. per 100 ml.)	—	—	—	13,000	17,000	22,000

[1] Grab samples taken June 11, 1952, at 4-hr. intervals.

minimum, and maximum correspond to 56.2, 26.5, and 76 per cent of saturation, respectively. Similarly, at station 4.35 the dissolved oxygen content averaged 6.17 p.p.m., with a minimum of 5.5 p.p.m. and a maximum of 7.6 p.p.m. These average, minimum, and maximum concentrations correspond to 69.2, 62.3, and 82 per cent of saturation, respectively.

Normally, these oxygen saturation deficit observations would be taken as the degree to which oxygen had been depressed by the blowdown discharges. The dissolved oxygen data recorded upstream during the sampling period casts some doubt as to the validity of these deductions. It was shown (Table II) that the oxygen content at upstream station 10.30 varied considerably during daylight hours (maximum 10.8 p.p.m.) as compared to night measurements (minimum 6.8 p.p.m.) These variations at station 10.30 constitute a high of 115 per cent of saturation and a low of 75 per cent of saturation attributable only to the indirect effects of sunlight and darkness. These apparent factors should be taken into consideration at the downstream sampling stations. Other test results at the same station are given in Table III.

Recalculation of oxygen deficits or per cent saturation at station 9.65, where samples were gathered during darkness only and on the basis of the upstream oxygen content of 6.8 p.p.m. as the available concentration, results in dissolved oxygen saturations of 73.5, 34.0, and 100 per cent for the average, minimum, and maximum recorded oxygen concentrations, respectively. Sampling at station 4.35 was done during daylight hours and, consequently, the dissolved oxygen saturation as recorded for this station would be valid.

TABLE III.—Analysis of 24-Hr. Composite[1] of Water Upstream from Yorklyn (Station 10.30)

pH	7.1
Alk., as $CaCO_3$ (p.p.m.)	46
Acid, as $CaCO_3$ (p.p.m.)	2
Susp. sol. (p.p.m.)	18
B.O.D. (p.p.m.)	1.6
CO_2 (p.p.m.)	1.7
NH_3-N (p.p.m.)[2]	0
NO_3-N (p.p.m.)	2.34
Chloride, as Cl (p p.m.)	17
Iron (p.p.m.)	0.5
Phenol (p.p.m.)	0.014
Color:	
P.p.m.	5
Relative	25

[1] Composite of samples 1–6 (Table II).
[2] Composite of samples 1, 2, and 3 gave NH_3-N of 0.09 p.p.m.

Discussion

The stream purification attributable to natural causes, as previously indicated, is surprisingly good. The biological balance within the stream was completely disrupted (2), but the effect of slime growth on the stream bottom should not be disregarded. Unfortunately, slime growth was insufficiently investigated to evaluate its degree of influence. The degree of purification found within this 5.3-mi. stretch of stream may appear more reasonable if some reflection be given to observed conditions at upstream sta-

tion 10.30. The pollution load reaching Red Clay Creek in the Kennett Square, Pa., area is in all probability, substantial, but the residual pollution reaching the State of Delaware after only 4 mi. of stream flow was quite low, as was shown by the biological, chemical, physical, and bacteriological analyses made at station 10.30 (2). Apparently, self-purification within a rapidly moving body of water may be appreciable, and consideration of this natural ability should not be neglected.

The oxygen deficit below the plant was notably less during the sampling period than one would at first surmise if the variable dissolved oxygen within the stream throughout the day be taken into consideration. A stream has the ability to replenish its deficient oxygen by reaeration. The oxygen level in Red Clay Creek was quickly returned to normal as soon as the peak blowdown discharges moved downstream. Reaeration is affected by many factors, such as temperature, degree of undersaturation, depth, impoundments, dams, mixing, etc.

The rate of reaeration for Red Clay Creek between Yorklyn and Wooddale was calculated from the data accumulated on June 11, 1952. The average dissolved oxygen and temperature measurements of samples taken at 0.5-hr. intervals were used as the deficits observed in the stream, upstream (station 9.65) and downstream (station 4.35), as affected during the blowdown discharge period. The stream B.O.D. of 50 p.p.m. at station 9.65 was determined from the composite consisting of 10-min. samples collected during the 3.5-hr. period of sampling. The time used in the calculations was taken as the stream flow time, that is, 14.5 hr. or 0.605 days. The deoxygenation constant (K_1) was assumed to be 0.1. Based on these assumptions, the reaeration constant (K_2) was found to be 0.389, or approximately 0.4. Other investigators have estimated K_2 values to be 0.3 to 0.5 for swift streams. Red Clay Creek certainly can be classified as a swift stream, and the estimated K_2 value of 0.4 strengthens the observed high degree of stream self-purification.

Summary

A study was made of pollution entering Red Clay Creek and its effect upon the quality of the receiving waters. The capability of self-purification within Red Clay Creek, based on chemical and physical measurements, under the existing conditions was estimated.

Conclusions

1. Determination of stream flow time can be estimated by observing strong fiber mill blowdown discharge movements, utilizing alkalinity and color measurements as indicators of these movements.

2. Stream self-purification, as measured between Yorklyn and Wooddale, Del., during a stream flow time of 14.5 hr. and a distance of 5.3 mi., resulted in approximately 60 per cent reduction of the B.O.D.

3. Stream self-purification during the time and distance indicated resulted in a reduction of approximately 70 per cent of the color, but only 10 per cent of the suspended solids.

4. Self-purification as measured in Red Clay Creek could not be attributed to suspended solids removal or biological activity, but only to the effects of direct oxidation and possibly to slime growth on the rocky stream bottom.

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THE OPERATOR'S CORNER

CONDUCTED BY HERBERT P. ORLAND

SAFETY IN SEWER MAINTENANCE—WHOSE RESPONSIBILITY? *

BY DONALD E. HALL

Safety Engineer, Division of Industrial Safety, Department of Industrial Relations State of California

Because of the increased demand for sanitary sewer service, as well as the increased loads imposed by garbage disposal units and industrial process wastes, safe operation and maintenance of existing sewer systems and sewage treatment plants is becoming increasingly more difficult. The increased work load, besides imposing new hazards, results in much greater exposure of the work crews to hazards normally present in work of this type.

Work in manholes, such as rodding and cleaning of the lines, as well as work in wet wells and dry wells, results in a greater exposure to such dangers as noxious gases and oxygen deficiency. Much of the work must be done on an emergency basis; that is, the lines must be cleared or the pumps unclogged because a certain part of the system has suddenly ceased to function.

Industry also complicates this problem of providing safety for sewer maintenance men by reason of the various by-products that intentionally or accidentally get into the sewer system. Even if such unwanted substances as wastes oils, chemicals, and solid refuse are kept out of the plant discharge, the normal sewage load on laterals and trunk lines increases the job of the maintenance crew.

Flat grades may result in sewer lines that are literally digestion units full of slow-flowing sewage. Release of the extremely toxic gas hydrogen sulfide, along with other gaseous products of sewage digestion, usually is accompanied by an equally hazardous deficiency of oxygen in the sewer atmosphere.

Employee Also Responsible

The question is not whether or not sewer maintenance work is hazardous—it is recognized as being extremely so—but of how this type of work can be done as safely as possible, and who is responsible for seeing that it is performed under those conditions.

In California the Labor Code applies to all types of employment, and to establishments with one or thousands of employees. In addition, the provisions of the code not only set forth the responsibilities of the employer, but also those of the employee. In other words, the California law makes safety a joint enterprise, with the employer and the employee constituting a team for obtaining safety in employment, and with each being responsible in his own way for the safe conduct of the work being done. In general, the employer must furnish employment

* Condensed from a paper presented at the 1953 Annual Meeting, California Sewage and Industrial Wastes Assn.; Santa Barbara, Calif.; April 22–25, 1953.

and a place of employment that is safe, but the employee is legally responsible for using the safety equipment and safeguards that are furnished him, as well as performing his job in the correct, safe manner prescribed by the employer.

Specific Hazards

Perhaps the most important Safety Order promulgated under the code is that applying to work being done in confined spaces. It requires, among other things, that persons working in confined spaces shall be protected from poisonous or noxious gases, or from the lack of oxygen, by ventilation or suitable respiratory equipment. Also, that employees working in confined spaces wear suitable safety belts or harnesses, connected to a lifeline secured outside the entry and attended by sufficient personnel to pull the endangered employees to safety in event of an emergency.

Safety Lines

Such a safety line system is a primary requirement for safe operation where employees enter manholes or other enclosed or underground structures. If the belt is of proper design, and if the belt and lifeline are properly worn, the employee can be removed from the manhole at once if he is seen to be in trouble. This means that the employee tending the lifeline must be in constant contact with the person working in the manhole, either by visually keeping the exposed worker under observation for signs of distress or by vocal contact at frequent intervals.

No employee should ever enter any manhole or similar confined space—at any time or for any reason—unless he is protected by such a safety line system. It is of utmost importance that all supervisors enforce this rule and provide sufficient sound lines and clean safety harnesses for all personnel so engaged. It is just as important, however, that the men themselves accept the use and wearing of these harnesses and lines as a very necessary part of the maintenance work.

Ventilation

A second Safety Order of primary importance is that requiring the furnishing of adequate ventilation. In locations where regular work operations are carried on, the ventilation equipment must be permanently installed. In locations where operations are on a casual basis, as in manholes, portable equipment is suitable if of adequate capacity. The criterion is removal of poisonous, noxious, or oxygen depleted air, and provision of wholesome breathable air.

Basic Responsibility

As previously set forth, both the employer and the employee have their separate responsibilities in this matter of safety. The fact remains, however, that unless the employer furnishes the required safety measures and devices, and then follows up with instruction and supervision to see that such safety measures and devices are observed and properly used, he may lay himself open to legal action in the event an employee is injured because of the lack of such safeguards. The hazard confronting the employer is as real a one as that facing the employee, but it is a hazard he can protect himself against by an intelligent safety program. Such a safety program would include as essentials:

1. Guarding of all mechanical devices.
2. Furnishing of adequate ventilation and protective devices, such as lifelines.
3. A schedule of repair and maintenance work for sewer system equipment (for example, foot rungs in manholes, ladders, passageways, etc.) Also, a schedule of maintenance that will

assure clean, sanitary, and safe protective devices.

4. A safety training and indoctrination course for all employees, as an integral part of the work week. Safety suggestions from employees should be encouraged and rewarded.

5. A "get tough" attitude must be used by management to enforce the applicable safety orders. Employees should never see a "tongue-in-cheek" attitude toward safety on the part of management. The most valuable asset a foreman can give a safety program is his compliance and good example.

Summary

In summary, safety is not an abstract quantity, but a way of life to live by from day to day to protect the funds of the employer and the lives of the employees. In this program both the employer and the employee have a place, but the responsibility for safety rests with intelligent, progressive management.

AN OPERATOR LOOKS AT DIGESTER DESIGN STANDARDS

By Frank I. Vilen

Superintendent, Sewage Treatment Plant, Kenosha, Wis.

Separate sludge digestion is a recurring and lively topic for discussion whenever sewage treatment plant operators meet. Furthermore, because the treatment literature is replete with authoritative studies of digestion, it is with no little hesitation that I, as an operator, venture to express some thoughts on the subject. The urge is impelling, however, because trouble with digestion and digester operation is an ulcer which gnaws at the peace of mind of many treatment plant operators, and it is my opinion that much of the difficulty stems from inadequate design. If, as a result of this emanation, a hue and cry is raised which will forever banish me to dwell among my own sludge beds, so be it.

This discussion is confined only to the type of treatment and facilities provided at the Kenosha, Wis., plant (with which the author is most familiar), and is concerned mostly with the production and utilization of sludge gas. It is hoped that others will find some parallel in their own situation.

The Kenosha primary treatment plant has a design flow of 10 m.g.d. After comminution, the sewage is lifted to the operating levels against a 25-ft. head. A grit removal unit, a pair of flocculators, and four clarifiers follow, from which the settled sludge is pumped to a pair of digesters, each with a capacity of 83,000 cu. ft. Both digesters are of the floating cover type, with one equipped with a gas holder of 45,000-cu. ft. capacity. The digesters can be operated either in series or parallel, but conditions peculiar to the plant make it preferable to operate them in parallel. The digesters are heated with the conventional hot-water coil system.

The design anticipated utilizing sludge gas as fuel for pumping engines, and for heating the digesters and the plant structures. With the present flow of about 16 m.g.d., however, the daily gas demand for pumping alone is 42,000 cu. ft. Utilization of engine heat is provided by means of water-to-water and exhaust heat exchangers.

A widely accepted minimum standard for primary sludge and heated digesters is 2 to 3 cu. ft. per capita. In

1941, the first full year of plant operation, per capita digestion capacity was 3.4 cu. ft.; on the basis of estimated suspended solids population equivalent, it was 2.5 cu. ft. per capita.

In 1952 the capacity on the basis of population alone was 3.0 cu. ft., and on suspended solids population equivalent it was 2.2 cu. ft. Thus, 12 years after the plant was placed in operation, it is on the ragged edge of having just barely enough digester capacity according to these minimum standards.

Perhaps this is a good time to interject a word or two about design standards. Purely as a personal opinion, I wonder if establishing minimum standards as a guide for design does not often lead to false economies in order to make sewage treatment more attractive to a prospective buyer. There are instances where a new plant has been found to be inadequate to do the job which was expected, although perhaps some treatment is better than no treatment at all.

For a period of several years, the Kenosha plant was operated at about 45 per cent of the design flow, with a major portion of the city's sewage bypassed due to toxic copper wastes. During this period, available digester capacity was, of course, proportionately greater. Gas production averaged 11 cu. ft. per pound of dry volatile solids added to the digesters.

In 1948, the copper problem was partially solved, and all of the city's sewage was diverted to the plant. The rate of gas production since that time has averaged 6.6 cu. ft. per pound of dry volatile solids added to the digesters.

Gas production in 1952 averaged 32,250 cu. ft. per day. Had it been possible to maintain the former rate of gas production, there would have been available a daily average of 54,000 cu. ft., and it would not have been necessary to buy $3,700 worth of natural gas to supplement the short supply. Over a three-year period, the cost of additional purchased natural gas has averaged $2,700 annually. Assuming a useful digester life of 30 years, this annual expenditure would buy a lot of digester capacity, and would have bought quite a lot more back in 1940 and 1941.

From personal experience, the factors that adversely affect digestion and sludge gas production at Kenosha can be enumerated in the order of their importance as follows:

1. Inadequate digester capacity.
2. Loss of volatile matter as per cent of total sludge solids because of storm flow "washouts."
3. Colder winter sludges, with consequently more shock to the digesters.
4. Presence of toxic copper wastes. (The 1952 average in digester sludges was 3,700 p.p.m. as copper in dry solids. It is felt that these amounts can be tolerated and still get good digestion, provided other factors are favorable.)
5. Inability to maintain optimum sludge temperatures during the winter months.

This concern with the production of sludge gas results from conditions imposed in the original plant design. On the basis of volatile matter destroyed, it seems to make little difference in the drying qualities or ultimate disposal of sludge whether digestion efficiency is 40 or 50 per cent. What we are interested in is an adequate supply of fuel to meet the plant demand.

Our experience indicates that an additional criterion should govern digester capacity requirements. A good question for designers should be: "Is sludge gas to be utilized, and to what extent?" If the answer is "Yes," I believe present standards are inadequate. In our case, capacities should have been doubled.

INTERESTING EXTRACTS FROM OPERATION REPORTS

Annual Operation Report of the Niles, Mich., Sewage Treatment Plant for the Fiscal Year Ended July 31, 1952 *

By Charles V. Clem, *Superintendent*

Gas production during the year was higher than previously, presumably as a result of cutting ground-water infiltration to a minimum and reducing sewage septicity through a systematic sewer cleaning program.

Operating activities were mostly routine. However, the chimney had to be increased 15 ft. in height to eliminate downdrafts. Also, the insurance company required a change in the fuel oil line from the storage tank to the boiler, including an anti-siphon valve, a two-stage pump, and a return line to the tank.

Considerable landscaping was done during the year, adding greatly to the appearance of the grounds.

Table I is a summary of operation data for the year.

* For last previous extract see This Journal, **24**, 7, 916 (July, 1952).

TABLE I.—Summary of Operating Data for Niles, Mich., Sewage Treatment Plant for the Fiscal Year Ended July 31, 1952

Item	Average	Item	Average
Rainfall, total (in.)	54.52	Dry solids (lb.)	2,220
Trib. population, est.	14,000	Vol. solids (%)	44
Sewage treated (m.g.d.)	2.9	Vol. solids, dry (lb.)	950
Grit, est. (cu. ft./m.g.)	3.1	Supernatant liquor:	
Total solids:		Amount (g.p.d.)	5,280
Raw sewage (p.p.m.)	710	Total solids (%)	0.32
Effluent (p.p.m.)	565	Vol. solids (%)	0.48
Reduction (%)	17.5	Digested sludge:	
Suspended solids:		To beds (gal.)	136,690
Raw sewage (p.p.m.)	165	Total solids (%)	14
Effluent (p.p.m.)	80	Total solids, dry (lb.)	162,300
Reduction (%)	42	Vol. solids (%)	52
Settleable solids:		Vol. solids, dry (lb.)	85,150
Raw sewage (ml./l.)	7.8	Gas production:	
Effluent (ml./l.)	1.25	Cu. ft. per day	8,050
Reduction (%)	84	Cu. ft. per lb. vol. solids	10.8
B.O.D.:		Cu. ft. per capita per day	0.53
Raw sewage (p.p.m.)	92	Chlorine:	
Effluent (p.p.m.)	58	Used (lb./day)	100
Reduction (%)	35	Residual in effl. (p.p.m.)	0.51
Raw sludge:		Oper. and maint. cost ($):	
Amount (g.p.d.)	3,460	Total	37,050.56
Total solids (%)	6.3	Per m.g.	34.63

Twelfth Operation Report of the Marion, Ind., Sewage Treatment and Garbage Disposal Plant for the Year 1952 *

By E. Stuart Savage, *Superintendent*

One of the major additions of the year was the purchase of two new load-packer collection trucks for Garbage Department use, which permitted tin can collections to be performed by that department, instead of by the Street

* For last previous extract see *Sewage Works Jour.*, **20**, 6, 1111 (Nov., 1948).

Department as formerly. During the year, 1,522 tons of garbage were collected and disposed of at the sewage treatment plant. In addition, 490 tons of tin cans were collected and hauled to the city dump from June through December.

The long-needed second grit collector was purchased and installed. Replacement collectors and headers for the final settling tanks were purchased for installation when the tanks are drained.

A new 3-ton International truck chassis was purchased to replace the 1945 Reo used as the 1,000-gal. sludge truck. A dump body was mounted on the Reo for use in hauling grit, dried sludge from the lagoon, and other general purposes. The 1941 Ford pick-up truck also was replaced with a 1952 International pick-up.

The carborundum diffuser tubes were removed, cleaned in chromic acid, and replaced. The gas engines driving the raw sewage pump and No. 4 blower were dismantled for inspection and overhaul. The raw sewage pump engine had operated 6,210 hr. since the previous shutdown, and No. 4 blower engine had operated 6,197 hr. The comminutors were raised and overhauled and the digester circulator pump was completely overhauled. Parts of the service building and compressor buildings were repointed where rain water had been entering. All other structures and equipment were regularly inspected and maintained.

Another major undertaking of the year was the operator's training program that was started under the direction of Ray Strickland, Chief Operator. The plant personnel get together at the plant one evening each month. Movies, lectures, and discussion of sewage treatment methods and problems make up the program. These sessions have been entirely voluntary, but the attendance has been good. The value of this program has been apparent by the attention paid to operating techniques and plant housekeeping since the training program began.

Operation data for the year are summarized in Table II.

TABLE II.—Summary of 1952 Operating Data at Marion, Ind.

Item	Average
Rainfall (in.)	34.91
Tributary population-equivalent:	
Susp. solids (0.22 lb. per cap.)	23,100
B.O.D. (0.17 lb. per cap.)	21,200
Sewage flow (m.g.d.)	5.07
Suspended solids (p.p.m.):	
Raw	122
Settled	125
Final	19
Removal (%)	84.5
B.O.D. (p.p.m.):	
Raw	88
Settled	80
Final	10
Removal (%)	88.2
Activated sludge:	
Ratio return sludge to flow (%)	26.4
Detention in aeration tanks (hr.)	4.31
Mixed liquor susp. sol. (p.p.m.)	2,648
Return sludge susp. sol. (p.p.m.)	10,859
Return sludge per cent volatile	61.2
Sludge index (Mohlman)	92
Cu. ft. air per gal. raw sewage	0.75
Cu. ft. air per lb. B.O.D. removed	1,386
Raw sludge data:	
Dry solids (1,000 lb. per month)	293.8
Total solids (%)	4.30
Volatile solids (%)	60.4
Digested sludge data:	
Wet sol. removed (1,000 gal. mo.)	253.7
Dry solids removed (tons per month)	55.4
Total solids (%)	4.82
Volatile solids (%)	48
Garbage disposal:	
Green garbage hauled to plant (tons per month)	
Dry garbage solids to digester (1,000 lb. per month)	39.0
Volatile solids (1,000 lb. per month)	34.4
Digester gas (cu. ft. lb. vol.)	7.27
Cu. ft. per capita per day	2.19
Treatment costs (plant oper. only):	
Per million gallons ($)	33.02
Per capita for the year ($)	3.30
Per 1,000 lb. B.O.D. rem. ($)	51.20

Annual Report of the Dayton, Ohio, Division of Sewage Treatment for the Year 1952 *

By L. T. Hagerty, *Superintendent*

Plant Units

Most of the sewage from the city flows to the Broadway pumping station, where it passes through mechanically-cleaned bar screens before being pumped to the treatment plant through about 1 mi. of 54-in. force main. About 6 per cent of the total sewage flows to the Westwood pumping station, where it passes through manually-cleaned bar screens and is pumped to the plant.

At the plant, grit is removed in two 40-ft. diameter, 15.5-ft. wall depth detritors (37,000-cu. ft. capacity; detention, 15 min. at 26 m.g.d.). These same units float off the grease, which is removed manually and incinerated. The grit is mechanically cleaned in two grit channels, then hauled to the grit dump for burial.

Six Imhoff tank units, designed in 1928 for a flow of 26 m.g.d. at 1.5-hr. detention, averaged 42.37 m.g.d. during 1952, with a high hourly flow of 72.72 m.g.d. Despite the heavy overload, these tanks removed 50.2 per cent of the suspended solids. Only 11.2 per cent of the settled solids were left in the Imhoff digestion compartments, the remainder being distributed to the digesters, drying beds, and lagoons.

Six digesters are 50 ft. in diameter and contain about 40,000 cu. ft. each. The remaining four digesters are 85 ft. in diameter and contain about 165,000 cu. ft. each. Sludge from the digesters is dried on open beds and by mechanical drier, for use as fertilizer, both as a saleable product and on the adjacent city-owned farm.

Of the 20 165-ft. diameter trickling filters, 12 are equipped with low-rate distributors and 8 with high-rate distributors.

The six 80-ft. diameter final settling tanks (total capacity 2.038 m.g.) provided an average detention period of 1 hr. 7 min. for the 1952 flow. Suspended solids and B.O.D. removals in these units were excellent despite the relatively short detention period.

Maintenance

Repairs to the grit channels were only made to the point necessary to keep these units in operation until their projected abandonment upon installation of new grit tanks.

Extensive repairs were made to the Imhoff tank walkways, and more than 25 per cent of the scum box covers were replaced. Little maintenance is planned on these units until after the new primary sedimentation tanks are placed in operation. Then they will be given a major overhauling.

Many gas leaks occurred during the year because of broken pipes and pipe disintegration. These were eliminated by pipe replacement and abandonment of all underground gas storage. The Hortonsphere gas holder was painted with one coat of corrosion-resistant primer and one coat of fume-resistant gray paint. A program of blowing the water out of the Hortonsphere daily has eliminated condensate water trouble in the rest of the gas system.

The roofs of the floating covers of the small digesters have rotted so badly that they collapsed under their own weight. The cause was apparently condensation of moisture on the under side. One roof was replaced in 1951, two in 1952, and it is planned to repair the other three in 1953. New lumber is being creosote treated before use.

Rusting of the single-wall vents on the digester heat exchangers seems to have been eliminated by installation of new double-wall vent pipes.

* For last previous extract see *Sewage Works Journal*, 20, 2, 330 (Mar., 1948).

Snail shells washed out of the trickling filters during high flows accumulated in the sludge hoppers of the final tanks in such quantity as to solidly plug the 6-in. sludge lines. As there seemed no way of eliminating the snails without upsetting the filters, each sludge line was tapped for a compressed air connection. By blowing air back through the lines at about 100 p.s.i., the lines can be kept clear without dewatering the tanks.

Operating data for 1952 are summarized in Table III.

TABLE III.—Summary of 1952 Operating Data at Dayton, Ohio

Item	Average
Rainfall, total (in.)	38.10
River flow (c.f.s.):	
Max. month, av.	8,481
Min. month, av.	357
Av. for all months	2,529
Tributary pop., equivalent	397,018
Sewage flow:	
Total (m.g.)	15,507
Av. daily (m.g.d.)	42.37
Av. max. hourly (m.g.)	1.86
Bar racks and detritus tanks (total lb. dry solids removed):	
Detritus skimmings	410,868
Detritus grit	730,427
Pumping screens	136,139
Suspended solids:	
Raw (p.p.m.)	263
Settled (p.p.m.)	131
Filter effluent (p.p.m.)	95
Final (p.p.m.)	36
Removal (%)	86.3
B.O.D. (5-Day):	
Raw (p.p.m.)	191
Settled (p.p.m.)	128
Filter effluent (p.p.m.)	48
Final effluent (p.p.m.)	24
Per cent reduction	87.4
Filter loadings:	
M.g. per day	42.37
M.g. per acre-ft. per day	4.32
B.O.D. (lbs./acre/day)	4,510.6
B.O.D. (lb./acre-ft./day)	614.8
B.O.D. (lb./1,000 cu. ft. filter media)	38.0
Material removed from Imhoff tanks (lb. dry solids/mo.):	
To digesters—12 mo.	274,452
To lagoon—1 mo.	193,400
To drying beds—5 mo.	38,680
Material removed from digestion tanks (lb. dry solids/mo.):	
To drying beds—11 mo.	107,040
To lagoon—12 mo.	444,470
Gas produced (1,000 cu. ft.):	
Digesters	36,767.2
Imhoff tanks	7,150.5
Total	43,917.7
Fertilizer operations:	
Operation costs ($):	8,049.83
Personnel	6,344.66
Equip., supplies	1,705.17
Total sales ($):	16,330.31
Profit ($)	8,280.48
Farm operations ($):	
Income	18,128.11
Expenditures	1,507.79
Profit	16,620.32
Sewage plant costs ($):	
Administration	14,999.38
Operation	97,865.13
Maintenance	21,864.61
Total	134,729.12
Net sewage plant cost ($)	126,314.64
Net sewage plant cost per m.g. sewage treated ($)	8.145

1953 CALIFORNIA WAGE SURVEY

At the 1953 Annual Meeting of the California Sewage and Industrial Wastes Association, the Prevailing Wage and Personnel Committee of that association released the results of its recent survey of prevailing wages in California sewage treatment plants. The data (Table I) are published in accordance with the recommendations of a special report on salaries (see THIS JOURNAL, **25**, 1, 110: Jan., 1953) to the Federation Board of Control.

Members of the California committee were: E. G. Studley, Chairman; J. B. Harrison, Vice-Chairman; R. Fenchel, James O. Groves, and E. G. Hager.

TABLE I.—Results of March, 1953, Survey of Prevailing Wages in California Sewage Treatment Plants

Location	Design Cap. (m.g.d.)	Present Pop.	No. of Empl.	Chief Operator		Asst. Chief Operator		Operators		Other Personnel, Except Clerks	
				Title	Salary ($/mo.)	No.	Salary ($/mo.)	No.	Salary ($/mo.)	No. and Type	Salary ($/mo.)
(a) Primary Treatment Plants											
U. S. Naval Depot—Seal Beach	0.25	1,290	3	Oper. water and sewage works	345	—	—	—	—	1 Machinist 1 Gen. helper	345 280
Calif. State Prison—Soledad	0.4	3,000	3	Supt. water and sewage plant	376	—	—	—	—	Inmates	—
Pt. Hueneme	0.5	3,900	1	Supt.	325	—	—	—	—	—	—
Concord	0.85	10,000	3	Supt. tr. plant	430	—	—	2	323	—	—
Lincoln Village—Stockton	1.0	6,400	2	Plant supt.	337	—	—	—	—	1 Semi-skilled	264
Solano Beach, Vista, Ramona, Rancho Santa Fe	1.0	11,800	2	—	—	—	—	2	327	—	—
Manteca	1.5	4,000	2	Supt.	310	1[1]	270	—	—	—	—
Tulare	1.5	12,500	3	Supt. util.	375	—	—	1	252	—	—
								1	246		
Goleta	1.5	7,500	2	Chief oper.	320	1	300	—	—	—	—
Antioch	1.6	13,000	2	Chief oper.	335	—	—	1	320	—	—
Ventura	2.0	18,500	3	Supt.	367	—	—	1	298	—	—
								1	247		
Hanford	2.41	10,028	4	Chief oper.	299	—	—	3[2]	273	—	—
Monterey	4.0	20,000	2	Operator	369	1	307	—	—	—	—

[1] Assistant. [2] Shift operators. [3] Acting as chief operator. [4] Mechanic-operator. [5] Operating engineers. [6] Junior operating engineers. [7] Per day. [8] Lead operators. [9] Power plant operators. [10] Plant operators. [11] Assistant plant operators. [12] Light equipment operators. [13] Skilled. [14] Part time. [15] Night operator. [16] Plus $25 for car use. [17] Per hour. [18] Same men also run water system and gas and electric distribution systems. [19] Weekend relief. [20] Same men also operate water system. [21] Highest repairs pumps, others clean sewers. [22] Salary revisions pending. [23] Plus $25 for weekends. [24] Plus house and other benefits. [25] Foreman. [26] Senior attendant. [27] Attendants. [28] Apprentice operators. [29] Includes an engineer superintendent of sewage treatment at $842 and an assistant engineer superintendent of sewage treatment at $755. [30] Senior sewage plant operators: day $440/545, night $464/575. [31] Chief diesel plant operator. [32] Senior diesel operators: day $375/464, night $395/489. [33] Diesel operators.

TABLE I.—Continued.

Location	Design Cap. (m.g.d.)	Present Pop.	No. of Empl.	Chief Operator		Asst. Chief Operator		Operators		Other Personnel, Except Clerks	
				Title	Salary ($/mo.)	No.	Salary ($/mo.)	No.	Salary ($/mo.)	No. and Type	Salary ($/mo.)
(*a*) PRIMARY TREATMENT PLANTS—*Continued*											
Menlo Park	4.0	33,000	4	Asst. dist. eng.[3]	500	1	341	2	298	—	—
San Mateo	5.0	50,000	4	Operator	392	1	348	—	—	1 Laborer	298
						1	322				
Wilmington–San Pedro	7.0	90,000	8	Ch. sew. tr. pl. oper.	395/489	—	—	3	288/355	4 Attendants	259/319
Santa Cruz	7.5	22,000	5	Chief oper.	280/337	—	—	4	233/280	—	—
Oro Loma San. Dist.	8.4	105,000	8	Chief oper.	550	1[4]	390	5	350/370	1 Laborer	280
San Bernardino	9.0	90,000	7	Chief oper.	411	1	313	4	299	—	—
								1	273		
Redwood City	10.0	40,000	6	Chief oper.	332/415	—	—	5	266/332	—	—
Orange Co. Joint Outfall Sewer	10.0	120,000	14	Plant supt.	400	1	350	5	330	4 Chlor. oper.	320
										1 Utility man	280
										1 Chemist	400
										1 Asst. chem.	300
Bakersfield	16.0	45,000	7	Supt.	507	—	—	—	—	1 Mechanic	397
										5 Attendants	327
Fresno	20.0	100,000	7	Ch. oper. eng.	428	1	385	4[5]	342	1 Laborer	284
Richmond–Sunset Plant—San Francisco	20.0	300,000	20	Ch. oper. eng.	430/510	—	—	6[5]	350/410	1 Chemist	490/580
										1 Water chem.	340/400
										3 Laborers	14.80[7]
								5[6]	310/370	1 Truck driver	21.44[7]
										1 Stat. eng.	325/450
										1 Janitor	240/280
Southeast Plant—San Francisco	30	400,000	45	Ch. oper. eng.	430/510	—	—	7[5]	350/410	1 Chemist	490/580
								27[6]	310/370	3 Water chem.	340/400
										5 Laborers	14.80[7]
										1 Janitor	240/280

TABLE I.—Continued.

Location	Design Cap. (m.g.d.)	Present Pop.	No. of Empl.	Chief Operator		Asst. Chief Operator		Operators		Other Personnel, Except Clerks	
				Title	Salary ($/mo.)	No.	Salary ($/mo.)	No.	Salary ($/mo.)	No. and Type	Salary ($/mo.)
(*a*) PRIMARY TREATMENT PLANTS—*Continued*											
San Diego	40.0	430,000	55	Tr. pl. supv.	417	5[8]	378	9[9]	360	5 Laborers	269
								10[10]	343	2 Constr. and Maint.	296
								6[11]	296		
North Point Plant—San Francisco	65.0	835,000	33	Ch. oper. eng.	430/510	—	—	6[5]	350/410	1 Chemist	490/580
								15[6]	310/370	2 Water chem.	340/400
										4 Laborers	14.80[7]
										1 Truck driver	21.44[7]
										1 Janitor	240/280
Oakland	128.0	384,575	48	Pump. pl. foreman	412	—	—	15[10]	350	1 Mech. formn.	459
				Sew. pl. foreman	412			11[11]	317	1 Repairman	391
								2[12]	332	1 Electrician	391
										2 Skilled lab.	317
										2 Util. lab.	283
										2 Gardener-jan.[13]	282
										1 Chief chem.	636
										1 Sr. chemist	486
										2 Asst. chem.	370
										2 Inspectors	350
										3 San. aides	317
County San. Dist. No. 2—Harbor City	160.0	1,600,000	26	Supt.	489/608	—	—	5[10]	319/395	1 Chief mech.	395/489
								11[11]	288/355	2 Machinists	319/395
										1 Chief elec.	355/440
										1 Gardener	233/288
										1 Laborer	264
										1 Sr. chemist[14]	395/489
										2 Chemists[14]	355/440

TABLE I.—Continued.

Location	Design Cap. (m.g.d.)	Present Pop.	No. of Empl.	Chief Operator		Asst. Chief Operator		Operators		Other Personnel, Except Clerks	
				Title	Salary ($/mo.)	No.	Salary ($/mo.)	No.	Salary ($/mo.)	No. and Type	Salary ($/mo.)
(*b*) Secondary Treatment Plants											
Lompoc	0.4	6,000	3	Ch. oper. and supt.	335	—	—	1[15]	240	1 Relief and maint.	260
Camp Matthews	0.4	9,000	7	Engineman	389	—	—	4	303/340	1 Leadingman engineman	486
Carmel	0.4	10,000	2	Pl. oper.	350[16]	1	300	—	—	—	—
Carpinteria	0.5	3,500	2	Operator	300	—	—	—	—	1 Relief man	1.00[17]
Kaiser—near Fontana	0.5	6,000	4	None	—	—	—	4	301	—	—
Minter Village, Bakersfield	0.5	10,000	3	Ch. sew. pl. oper.	433	—	—	2	330/350	—[18]	—
San Clemente	0.6	4,500	2	Sew. pl. supt.	330	—	—	1[19]	260	—	—[20]
Alisal San. Dist.	0.75	17,000	2	Chief oper.	315	—	—	1	300	—	—
Chino	1.2	6,000	1	Chief oper.[14]	182	—	—	—	—	Maint. work	—[17]
Anza Village	1.25	2,500	2	Operator	315	—	—	1	315	—	—[20]
Chico	1.68	5,000	1	Operator	321	—	—	—	—		
Laguna Beach	2.0	7,000	5	Operator	289	1[10]	298	—	—	3 Truck drivers[21]	270/315
San Luis Obispo	2.0	16,000	4	Sr. pl. oper.	317	—	—	3	284	—	—
McClellan Air Force Base	2.0	17,000	7	Sr. oper. eng.	385	—	—	4[5]	345	—	—
								2[5]	278		
Oceanside	2.0	18,300	4	Chief oper.	365	—	—	3	280	—	—
Modesto	2.0	20,000	12	Ch. sew. pl. oper.	261/317	—	—	6	274	2 Maint. men	288
										2 Laborers	243
Mt. Vernon San. Dist.	2.0	22,000	6	Dist. supt.	478	1	392	4	278/322	—	—
San Anselmo	2.0	35,000	2	Chief oper.	375	1	375	—	—	—	—
Oxnard	2.5	26,100	3	Chief oper.	—[22]	1	—[22]	—	—	1 Util. man	250
Tracy	2.75	14,000	3	Chief oper.	300	—	—	2	280	—	—

TABLE I.—Continued.

Location	Design Cap. (m.g.d.)	Present Pop.	No. of Empl.	Chief Operator		Asst. Chief Operator		Operators		Other Personnel, Except Clerks	
				Title	Salary ($/mo.)	No.	Salary ($/mo.)	No.	Salary ($/mo.)	No. and Type	Salary ($/mo.)
(*b*) Secondary Treatment Plants—*Continued*											
Indio	3.0	6,325	5	Operator	300	—	—	1	300	—	—
Corona	3.0	10,000	1	Operator	306[23]	—	—	—	—	—	—
Santa Maria	3.0	11,000	4	Supt.	332	—	—	3	292	—	—
Camp Cooke	3.0	19,000	6	Sew. pl. oper.	403	—	—	4	368	1 Plumber-mech.	386
Pomona	3.375	40,000	6	Ch. sew. pl. oper.	359	—	—	5	273/313	—	—
Colton	3.5	15,381	4	None	—	—	—	4	273/299	—	—
Napa	4.0	53,000	5	Plant supt.	425	—	—	4	325	—	—
Salinas	5.0	18,000	5	San. supt.	385[24]	—	—	4	288/322	—	—
Riverside	5.0	49,000	6	Supt.	415	—	—	5	324	—	—
Santa Rosa	5.0	54,500	6	Sew. pl. supt.	360/476	—	—	5	231/305	—	—
Palo Alto	6.0	33,348	5	Supt.	346/432	—	—	4	277/346	1 Laborer[14]	248/310
Santa Barbara	6.0	50,000	9	Supt.	420	1[1]	375	6	222/237	—	—
								1[25]	246		
Ontario	6.0	65,000	5	Sew. pl. foreman	388	—	—	1	312	2 Util. men	275
										1 Laborer	246
San Leandro	7.0	30,000	6	Supt. sew. tr.	503	—	—	1[26]	360	—	—
								4[27]	305		
Visalia	9.0	12,000	5	Supt. sew. tr. pl.	474	—	—	4	284	—	—
Stockton	24.0	74,159	17	San. disp. pl. supt.	505	—	—	8	361	1 Chemist	323/404
								5[28]	274/340	2 Laborers	274
Hyperion—	245.0	2,500,000	250[29]	4 Shift supts.:		3[30]		45[10]	288/375	61 Attend.	259/337
Los Angeles				Day	545/677	1[31]	440/575	5[32]	375/489	32 Maint. lab.	303
				Night	575/715		608	18[33]	319/417	1 Ch. chem.	440/545
										2 Chemists	355/440

TRITURATOR OPERATION IMPROVED BY RETIPPING OF TEETH

By John R. Szymanski

Superintendent, Sewage Treatment Plant, New Britain, Conn.

At the New Britain, Conn., sewage treatment plant the original (1936) design for handling screenings consisted of a mechanically cleaned bar screen, from which the screenings were shoveled into containers that were then wheeled about 30 ft. to be dumped into an incinerator compartment for disposal. This method was unsatisfactory for the following reasons:

1. Fluctuating deposits of screenings on the receiving tray required close attention.
2. Accumulating quantities of screenings on the receiving tray were unsightly and unsanitary.
3. Removal of screenings from the tray into the containers required both work hours and special handling.
4. Dumping of screenings into the incinerator required two men. Furthermore, it required close supervision to insure maintenance of proper temperatures in the incinerator for disposal of both sludge and screenings.

The foregoing reasons were considered evidence enough to instigate a study of the problem. After a thorough investigation, it was decided to install a standard triturator unit, to be attached to the existing bar screen tray.

Excessive Tooth Dulling

The unit was installed and placed in operation early in 1939. Theoretically it was going to solve all of the difficulties previously mentioned and provide an easier and cleaner way of handling the screenings.

During the first few weeks of operation the results were very satisfactory, the screenings being fed into the triturator without sorting and without undue loss of man-hours. It should be noted, however, that no provision is made for grit removal at the New Britain plant. During high flows large quantities of sand and gravel arrive at the plant and show up on the screenings tray.

Although in normal operation of the triturator it is to be expected that the cutting teeth will become dull, it was never anticipated that the dulling would occur as often as monthly. The cost, in labor and materials, of keeping the triturator teeth sharpened soon overshadowed all of the benefits derived from its operation. Experience showed that the cutting teeth furnished by the manufacturer could be resharpened only twice, after which they had to be replaced with new ones.

A study of the problem was made. This resulted in requests to the manufacturer for help. After studying the matter in detail, the manufacturer's decision was that the unit was performing satisfactorily, and that the answer to the problem was the removal of all grit and abrasives in the screenings.

It was not practical to follow the recommendations, yet it was desired to use the unit. Therefore, an extensive search was undertaken for the solution to this problem.

During this study an occasion arose to discuss the matter with a representative of The Carboloy Company. At his suggestion the standard teeth supplied

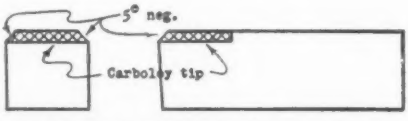

FIGURE 1.—Carboloy tips for triturator cutting teeth reduce wear due to grit abrasion.

by the manufacturer were taken to a local machine shop, where they were ground down and tipped with grade 55A Carboloy (see Figure 1), at a cost equal to that of two full sets of new teeth.

The tipped teeth were installed and have been in operation for three years. Material from the bar screen is fed without any sorting, yet recent inspection showed that the cutting edges are intact and require no attention.

As a note of interest the same procedure was followed on the comminutors at the Springfield, Mass., sewage treatment plant, with considerable savings in maintenance labor and materials.

TIPS AND QUIPS

No Nothin'!

A poignant message on the effects of stream pollution is carried by the International Nickel Company advertisement recently appearing in several farm and business periodicals (*Farm Journal*, August; *Successful Farming*, *Country Gentleman*, and *Pathfinder*, July; *Time*, June 15; and *Newsweek* and *U. S. News*, June 1). At the same time, modest tribute is paid to the sanitary engineer and his ingenuity and insight in dealing with pollution problems and turning "no fishing, no swimming, no nothin'" into "good swimming, good fishing, and good water."

Wire Fence Painting

Wire fencing of all types—even barbed wire—can be painted easily, quickly, and efficiently if a large-diameter roller with extra-long nap wool is used. Not only is good coverage obtained with a minimum of effort, but the paint is used on the fence instead of on the workers, shrubbery, and ground. For maximum benefit one should use one of the new rust-penetrating paints, but be sure to first knock off any loose rust scale with a piece of sheet metal or old rubber hose.

New Maggot Destroyer

A new product containing lindane and pentachlorophenol is claimed by the manufacturer to be the most effective fly-maggot killer known, as well as being an efficient deodorizer. Recommended use for the product is by spraying of insect breeding sources in refuse, garbage cans, etc., but the properties of the compound also should make it a valuable aid in eliminating fly-breeding in sludge beds.

The product, known as M-4-M (Murder for Maggots), is made by Knox Chemical Co., Dept. S-5, 165 W. Wacker Dr., Chicago 1, Ill.

Plastic Diaphragms for Pressure Relief Valves

A new material for replacing diaphragms in pressure relief valves has been discovered by John Allsop, Superintendent of the Herrin, Ill., sewage treatment plant. According to the May, 1953, issue of *The Digester*, diaphragms made from discarded plastic raincoats have been reported as very successful.

Suds Control

Coincident with the introduction of the detergent "Tide" into the district in September 1952, a marked increase was noted in the froth accumulation on the aeration tanks at the Clyde Park sewage treatment plant in Motherwell, Scotland. According to J. McNicholas,* manager of the plant, the

* McNicholas, J., "Disposal of Foam on Aeration Tanks." *Water and San. Eng.* (Brit.), **3**, 458 (1953).

suds reached a 14-ft. height above water level, or "more than enough to constitute a nuisance."

Increasing the mixed liquor solids to as high as 2,450 p.p.m. (about 700 to 1,500 p.p.m. are normally carried) seemed to have little effect. Even this concentration would be difficult to maintain in good condition during summer months, because of the existing limitations on air availability.

Froth control was finally achieved by use of a "Rainmaster" spray, fed by a pump supplying 50 g.p.m. at 25 p.s.i. to the 7/8-in. nozzle. The spray machine throws a jet of water that impinges on a drive wheel of the Pelton type, the wheel serving the dual purpose of breaking the jet into a spray and driving a gear to rotate the nozzle head on the base. An effective spray range of about 60 ft. is achieved, with spray head rotation at about one revolution in 4½ min.

The spray is moved about the aeration tanks to suit conditions of froth formation, wind, etc. The excessive froth has been controlled at this particular plant by operation of the spray for 25 to 30 min., but within 20 to 25 min. after the spray is shut off the suds have reformed to a depth of about 3 ft.

Observations indicate that the frothing characteristic of the aeration tanks is not simply smothered and transferred to the outlet stream, as no objectionable froth formation is apparent on the river.

Colored Anti-Rust Paints

Now available in red, gray, and green, in addition to the standard black, aluminum, and clear, Rustrem anti-rust paint is claimed by the manufacturer to stop rust completely in one application. For use on all metals, both indoors and out, the product is said to eliminate the necessity for wire brushing, scraping, or sandblasting because of its ability to penetrate rust layers and adhere tightly to surfaces beneath, forming a tight seal that resists moisture, temperature changes, chemicals, acids, and fumes. One coat of the product rustproofs for years, according to the manufacturer, Speco, Inc., 7308 Associate Ave., Cleveland 9, Ohio.

Nocturnal Insect Control

The fact that nocturnal flying insects are colorblind is a quirk of Nature being capitalized on by General Electric Co. lighting specialists in repelling or attracting them. Because the eyes of this type of insect are sensitive only to blue light and to the near-ultraviolet rays, bulbs producing such wavelengths are used to attract bugs.

Yellow is the color commonly used for anti-bug lamps, but red or orange would be just as effective for that purpose. Yellow, however, is more pleasing to humans and is a color to which the human eye is highly sensitive.

Among fluorescent lamps, the gold ones alone absorb the wavelengths that draw the bugs. Other fluorescent tubes are attractive to bugs, and blue and black fluorescent lamps have so much appeal that they are used in insect traps.

Advice to those seeking to minimize the annoyance and damage caused by flying insects during summer evenings includes the following:

1. Use yellow incandescent bulbs at entrance doors.

2. Illuminate outdoor work areas and picnic tables with hard-glass spot or flood lamps mounted at a distance, so that bugs attracted to the light source will drop to the ground instead of on workers or picnickers.

3. Illuminate the immediate work area with yellow lamps and place blue or white bulbs, or a black light insect trap, at a distance from where people work or congregate.

Analysts' Delight

One of the age-old problems confronting analytical chemists is that of getting a total of 100 per cent for the determined values without expending the time and labor necessary to do accurate work.

Through the years, various simplified methods of achieving the desired precision have been developed. Among these early laboratory aids were the "graphite-cellulose" (pencil-and-paper) method, the elastic slide rule, the parallax-producing attachment for rigid slide rules, the "inaccurate sample" method, the "variable constant" method, and the "adjustable percentage" method. Each, however, has demonstrated certain inherent undesirable qualities connected with its use.

Quite welcome, therefore, was a recent communication from W. D. Hatfield, Superintendent of the Decatur (Ill.) Sanitary District, indicating that as early as 1951 *The Chemical Bulletin,* a publication of the Chicago Section, American Chemical Society, had carried an article by James E. Thompson, describing two new compounds that would achieve the desired effects.

The first of these wonder compounds is thulium screwlate. Briefly, it takes on, by means of an intricately catalyzed reaction, both the chemical and physical properties of whatever constituent was originally present in too small a percentage. It is only necessary to add to the titration solution the required amount of thulium screwlate to make up any deficiency that exists.

When the total percentage is too high, the second compound, screwlium thulate, is recommended. As Thompson points out, this compound obviously must have negative weight, making it necessary to observe extreme caution to prevent containers being dashed against the ceiling. Use of the compound is relatively simple. When bubbled through a solution of the erroneously analyzed substance, it neutralizes its chemical properties and cancels its weight in proportion to the rate of addition.

Work also is reportedly "progressing on synthesis of a complex, screwlothulic bithulium screwlicate, which will have the combined properties of the two compounds incorporated in one compound by means of a bi-polar arrangement of a long-chain molecule so that either desired effect may be achieved by proper magneto-optic orientation of this complex molecule."

The stuff should be literally "worth its weight in gold"!

GRADUATE FELLOWSHIPS AVAILABLE AT RUTGERS

Several fellowships are available in the Department of Sanitation, Rutgers University, for part-time graduate work leading to M.S. and/or Ph.D. degrees. Stipends of $1,200 to $2,400 are offered. Requirements for appointments include a B.S. or M.S. in chemistry, chemical engineering, sanitary engineering, civil engineering, or biology. Further information on the fellowships is available from: Department of Sanitation, Rutgers University, New Brunswick, N. J.

Federation Affairs

MIAMI MEETING PLANNING TAKES SHAPE

Miami, gateway to the Caribbean and winter playground of the eastern United States, will be the locale of the Twenty-Sixth Annual Meeting of the Federation of Sewage and Industrial Wastes Associations, to be held October 13–16, 1953. Most of the technical and social events of the meeting, as well as the manufacturers' exhibit, will take place in the municipal Bayfront Auditorium, situated in beautiful Bayfront Park close to downtown Miami and several of the better hotels. The remainder of the programmed events are scheduled for a nearby hotel.

Preparations for the meeting are already reaching the "final details" stage, with many members of the host Florida Sewage and Industrial Wastes Association at work on arrangements.

Local Committees

The Local Arrangements Committee, under the general chairmanship of C. F. Wertz, Research Engineer of the Miami Department of Water and Sewage, is composed of the chairmen of the following subcommittees:

Registration Committee: D. P. Schiesswohl, chairman; A. Murphy, G. T. Lohmeyer, T. deS. Furman, and B. F. Snow.

Finance Committee: J. R. Hoy, chairman; R. Metcalf and C. E. Fiveash.

Entertainment Committee: A. B. Kononoff, chairman; M. N. Lipp and R. C. Hunderadt.

Ladies Entertainment Committee: N. Hoy, chairman; and J. L. Middleton.

Local Host Committee: B. F. Borden, chairman; P. Flanagan, F. A. Eidsness, W. J. Parks, D. B. Lee, W. A. Aultman, and J. E. Kiker, Jr.

Hotel Arrangements Committee: J. A. Stevens, chaiman; Ellis Phelps, C. H. Carothers, and J. W. Greenleaf, Jr.

Early Registration

To help early convention arrivals avoid the usual last-minute registration rush on October 13, the registration desk will be open in the Bayfront Auditorium lobby from 1 PM to 5 PM on Monday, October 12. Pre-registration is urged for all those in town during this period.

Announcement to Membership

All Active and Corporate Members of the constituent associations of the Federation were sent a formal announcement of the convention early in July. Contained therein are further details as to technical and social programs, registration, manufacturers' exhibits, suggested wearing apparel, and a post-convention tour to Havana, as well as a reservation form for hotel accommodations. (Hotel information also is given on the inside cover of this issue.) It should be noted that the meeting officially opens the morning of Tuesday, October 13, and closes at noon on Friday, October 16. Reservation of hotel accommodations should be placed directly with the FSIWA Housing Committee, 320 N. E. Fifth Street, Miami, Florida.

Reviews and Abstracts*

Rapid Sand Filters Improve Effluent. By A. E. J. Pettet. (Reprinted from *Municipal Review & Borough*) (1952).

Experimental rapid sand filters similar to water treatment rapid sand filters were set up at the Luton (England) sewage plant to filter trickling filter humus tank effluent. It was possible to backwash these filters with filtered effluent.

The filter bed consisted of sand 2 ft. deep graded so that the particle size ranged from 1/30 to 1/15 in. Humus tank effluent filtered at the rate of 100 to 180 gal. (Imp.) per square foot per hour lost 90 per cent of the suspended matter. The filtrate never had more than 5 p.p.m. suspended solids and occasionally there were no suspended solids. B.O.D. was also reduced 60 per cent by filtration. Sand gave better results in filtration than did anthracite as the medium.

Experiments were also conducted using a micro-strainer, a fabric of mesh containing 100,000 apertures per square inch. The rate of filtration was 80,000 g.p.d. (Imp.) per 13 sq. ft. of filter fabric.

No description was given of the method of disposal of solids from either of these two processes of secondary treatment.

K. W. Cosens

The Discharge of Gas Liquor into the Sewers. By E. H. M. Badger. *Jour. and Proc.*, Inst. Sew. Purif. (Brit.), Part 3, 201 (1950).

Gas liquor, amounting to about 20 to 50 gal. (Imp.) per ton of coal, was described as being the aqueous condensate formed in the manufacture and purification of coal gas and was derived mainly from (a) moisture in the coal, (b) reaction of oxygen and hydrogen, (c) steam applied to the retorts, and (d) the water fed to the ammonia scrubbers.

Ammonia, sulfides, monohydric phenols, polyhydric phenols, thiocyanate, thiosulfate, and cyanide are the principle constituents of final gas liquor.

The simplest and most satisfactory method of disposal is for the gas works to make a controlled discharge to the sewers of a liquor containing the minimum quantities of thiocyanate and polyhydric phenols and from which the free ammonia, sulfide, and cyanide have been removed by distillation. In some cases, further purification may be necessary or desirable. The methods available for producing an effluent suitable for treatment at the sewage works were discussed.

K. W. Cosens

Sludge Dewatering by Freezing with Added Chemicals. By G. S. Clements, R. J. Stephenson, and C. J. Regan. *Jour. Inst. Sew. Purif.*, Part 4, 318 (1950).

Pilot- and small-scale plant tests have shown that raw, activated, and digested sludges, alone or with chemicals, when slowly frozen and thawed can be dewatered by vacuum filtration in a matter of seconds. Slow and complete freezing was absolutely necessary for good results. Thawing could be done at normal temperatures or at high temperatures induced by steam, but stirring to hasten action led to increased filtration periods. Filter cakes had 23 to 30 per cent solids, and were porous and friable.

The following results, obtained by using a specially constructed freezing machine, show the improvement obtained in filtering sludge through freezing:

* Please send to Federation headquarters all periodicals, bulletins, special reports, etc., which might be suitable for abstracting in This Journal. Publications of public health departments, stream pollution control agencies, research organizations, and educational institutions are particularly desired. Address such material: Federation of Sewage and Industrial Wastes Assns., 325 Illinois Bldg., Champaign, Ill.

Method of Treatment	Chem. Conc. (p.p.m.)	Filtration		
		Time	Dry Solids	
			Cake (%)	Rate[1]
(*a*) Digested Sludge				
No chemicals, no freezing	—	120 min.	—	—
No chemicals, freezing	—	6 min.	23.6	7
Chlorine, freezing	250 Cl	3 min.	22.0	14
Chlorinated $FeSO_4$, freezing	250 Fe	80 sec.	26.9	31
Aluminum sulfate, freezing	100 Al	3 min.	26.9	9
Aluminum sulfate, freezing	200 Al	1 min.	25.6	27
Aluminum sulfate, freezing	500 Al	5 sec.	28.6	321
(*b*) Activated Sludge				
No chemicals, no freezing	—	10 min.	—	—
Aluminum sulfate, freezing	100 Al	30 sec.	20.0	24

[1] Pounds dry solids per square foot per hour.

Because of the rapid rate of filtration following freezing, an ordinary suction filter cannot be used and a discussion is included on planning and tests for improved filters. Design of freezing machines and experimentation is also discussed. To reduce freezing expense considerable work is being done to utilize the thawing of the sludge cake for pre-cooling. Supernatant liquids following settlement are not much stronger than ordinary sewage. W. A. Hasfurther

The Concept of Interface and Loading in Submerged Aerobic Biological Sewage Treatment Systems. By Gordon M. Fair and Harold A. Thomas, Jr. *Jour. and Proc.*, Inst. Sew. Purif. (Brit.), Part 3, 235 (1950).

The object of this paper was to formulate quantitatively some of the fundamental principles that pertain to the loading and performance of activated sludge plants and to extend these relationships to bioprecipitation units and contact aerators. It is desired to develop an appropriate loading parameter that can be used in the design and operation of sewage treatment plants for the purpose of approximating wanted removal efficiencies. Present parameters in use were listed as (a) referring to tank dimensions, (b) referring to air use, and (c) referring to sludge returned.

In describing the principles of aerobic biological sewage treatment it was stated that whenever sewage comes into contact with a suitable surface, whether it be a suspended particle, a piece of rock, or a sheet of asbestos-cement, there develop upon it growths of bacteria and other microorganisms that soon cover the superficies with a gelatinous or zoogleal film. This surface layer possesses the signal ability to transfer to itself substances that were dissolved or suspended in the sewage, or primary substrate. Having agglomerated this substrate and thereby formed a secondary substrate, the microorganisms next abstract from it the nutriment needed for their life activities and growth. Finally, the end products of their metabolism—including water, carbon dioxide, nitrate nitrogen, and sulfates—are rejected by the film, or secondary substrate, to the sewage that washes it.

There is inherent in the biological growths a considerable degree of self-limitation. This makes the process of biological sewage treatment very largely an exchange, transfer, or conversion process, rather than a process by which putrescible, dissolved, or finely-divided suspended or colloidal substances are fully destroyed. Instead they are removed from the liquid phase to a solid phase, in which they become settleable, at the same time as they serve their primary purpose of supporting

a microbial population that is active in agglomerating the sewage substrate. The self-limitation of the aerobic phase that is associated with the primary contact or interfacial process is due to the inability of oxygen to diffuse to the inner laminae of the activated floc, or surface film, in adequate amounts to keep them aerobic. Hence, the separation of excessive film growths from the flow, together with their stabilization in anaerobic digestion tanks if desired, make both for an effective and an economical combination of treatment processes.

If the mechanism of transfer of pollutants across biochemically active interfaces is the regnant process in aerobic biological sewage treatment systems, it follows that the degree of purification effected in these systems will depend on the factors of (a) mass of putrescible matter treated per unit of time; (b) mass of biologically active growth that contributes to the interface, whether attached or free-floating; (c) area and oxygen-absorbing efficiency of the air-liquid interface; (d) time of contact between the pollutional load and the biologically active interface; (e) degree of exposure of excessive filamentous growths to removal by hydraulic scour; and (f) the provisions made for the separation of excess agglomerated or detached material from the flowing sewage.

Formulas were developed for the activated sludge process, showing relationship of process efficiency in terms of a loading parameter. The loading parameter involves weights of putrescible solids in incoming sewage, the total weight of sludge, and ratios of volume of aeration tanks to rate of flow.

Similar mathematical expressions were developed, with some modification, for bio-precipitation and contact aeration systems. The loading parameters developed are not applicable to trickling filters.

A very worthwhile presentation of background material was also presented.

K. W. COSENS

The Influence of Synthetic Detergents on Sewage Treatment. BY JOHN HURLEY. *Jour. and Proc.*, Inst. Sew. Purif. (Brit.), Part 3, 249 (1950).

Plant-scale experiments were carried out at the Cloven Heath sewage treatment plant by applying 50 and later 75 p.p.m. of commercial Teepol, a synthetic detergent, to note effects that the detergent had upon the efficiency of the sewage treatment processes.

The plant is composed of two-stage primary sedimentation followed by trickling filters and secondary settling. It was possible to divide the flow through the plant into two equal parts, each of which would receive the same treatment. However, one part of the plant was dosed with detergents to give a comparison of detergent effects with normal effects.

For a 3-month period, 50 p.p.m. of Teepol was added to one-half of a flow of 450,000 g.p.d. (Imp.), then for approximately 1½ months 75 p.p.m. was added to half the flow.

These amounts were added to the plant influent and were in addition to detergent already present in the flow. A typical analysis during the first 3-month period of operation showed raw sewage (no detergent added) to contain 18 p.p.m., two-stage settling reducing this to 13 p.p.m., and filtration further reducing it to 4 p.p.m. For the flow dosed with Teepol, analysis gave 73 p.p.m. in raw sewage, 60 p.p.m. in primary effluent, and 5 p.p.m. in filter effluent. At the higher dose used, results were almost the same, the filters doing most of the removal work.

There were no physical indications of alterations in plant operations caused by detergent addition. No frothing was experienced.

It should be mentioned that tests were conducted using only one commercial detergent, Teepol, which is about 20 per cent active matter. The author noted that the detergent Lissapol passed through the sewage works practically unchanged, although tests were not conducted using the latter detergent. K. W. COSENS

Synthetic Detergents: Their Effects on Sewage Treatment and Water Supply. BY PETER G. ISAAC. *Water and San. Eng.* (Brit.), **3**, 11, 413, and **3**, 12, 453 (1953).

The author reviews and summarizes a number of articles (previously reviewed and abstracted in THIS JOURNAL) concerning the effect of detergents on sewage treatment and water supply. He points out that considerable care should be exercised in applying the results of laboratory-scale investigations to full-scale practice.

H. HEUKELEKIAN

Synthetic Detergents and Sewage Treatment. By J. R. Gaillard. *Jour. and Proc.*, Inst. Sew. Purif. (Brit.), Part 3, 276 (1950).

This paper represented the attitude of the profession in South Africa. Four laboratory-scale experiments were set up to test the effects of detergents on sewage treatment processes, as represented by the following four studies:

1. Settlement in Imhoff cones of crude sewage samples to which detergents had been added.
2. Effect of diluting soap and detergent laundry liquors with tap water.
3. Adsorption of a detergent by sewage sludge.
4. Effect of certain detergents on laboratory-scale activated sludge units.

The detergents used, in addition to soap, were Teepol (alkyl sulfate); Teepodol; Tergitol 7, 4, and 08; Santomerse (alkyl aryl sulfonate); Lissapol N (nonionic); and Fab (sulfated monoglyceride). Each experiment was described, data were presented for the analyses performed, and the following conclusions were drawn:

1. Mere addition of a detergent to a sample of sewage does not influence the quality of the settled sewage, as tested under laboratory conditions.
2. An important increase is likely to occur in the loading of biological units by the extensive use of certain household detergents in place of soap.
3. There is evidence that a portion of the detergent will be carried with the settled sludge into the digesters.
4. Detergents appear to be specific in their action. Although some have little apparent effect, others will certainly cause major difficulties in the operation of activated sludge units, even in concentrations as low as 50 p.p.m.

K. W. Cosens

Heat Treatment of Sewage Sludge. By C. Jepson and L. Klein. *Jour. and Proc.*, Inst. Sew. Purif. (Brit.), Part 1, 36 (1951).

A series of laboratory experiments, using mainly activated sludge, was conducted by heating sludges up to boiling temperatures with free liquid surface and noting the effects of concentration of solids, removal of supernatant, and other properties. A second series of experiments was also conducted, heating the sludge to higher temperatures under pressures up to 150 lb. per sq. in.

Densification of fresh activated sludge by three methods is shown as follows:

Item	Method A [1]	Method B [2]	Method C [3]
Before treatment:			
Volume of sludge (ml.)	1,000	1,000	300
Dry solids content (%)	0.71	0.71	0.71
Time required (hr.)	24	24	0.33
After treatment:			
Volume removed (ml.)	570	680	275
Volume removed (%)	57	68	79
Dry solids in sludge—per cent	1.41	1.84	3.11
Analysis of liquor (p.p.m.):			
Suspended solids	14	46	37
Total solids	1,050	1,500	1,500
Ammonia nitrogen	47.4	46.5	45.0
Organic nitrogen	20.4	122.0	75.0
Nitric nitrogen	0.0	2.1	1.5
Oxygen absorbed, 4 hr.	55.7	189	123
B.O.D., 5-day	96.6	544	273

[1] Simple settlement for 24 hr.
[2] Heated to 70°C. with stirring, settled 24 hr.
[3] Heat flotation at 90°C.

Summarizing ordinary pressure experiments, it may be said that flotation of sludge appeared to be better if carried out in narrow vessels. Temperatures may be varied between 70° and 98°C., working equally well with fresh or stale sludges. Water removed ranged from 50 to 80 per cent, but in all cases the resulting sludge appeared to be pumpable. The supernatant was about equal to the strength of medium sewage.

The heat treatment of sludges at high pressures makes it possible to quickly obtain sludges containing a considerably increased proportion of solid matter. Dry solids contents of sludges initially at 0.80 and 4.84 per cent were increased, respectively, to 2.49 and 7.80 per cent after heat treatment. The solid matter content depends largely on that of the original sludge, but also is influenced by the steam pressure applied and the time of application.

The heat treated sludge settles rapidly, separation usually being complete in less than 2 hr. The supernatant may contain up to 36 per cent of the original solids and 59 per cent of the original nitrogen.

The densified sludge filters readily, but subsequently possible digestion is inhibited.

K. W. Cosens

P.F.T. DIGESTER FLOATING COVER at Woodstock, Ill., Features Roof of Insulated Prefabricated Sections

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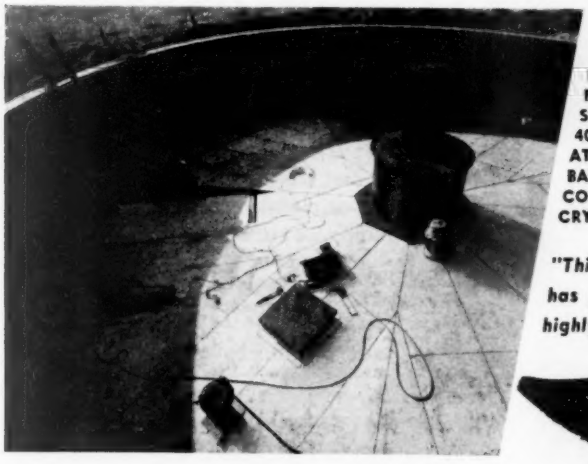

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Proceedings of Member Associations

CALIFORNIA SEWAGE AND INDUSTRIAL WASTES ASSOCIATION

The 25th Annual Convention of the California Sewage and Industrial Wastes Association was held at the Mar Monte Hotel, Santa Barbara, Calif., April 22–25, 1953. The total registration of 400, including 90 ladies, established a new attendance record.

Papers presented at the meeting included:

"Water Conservation, a By-Product of Industrial Waste Disposal Control," by John S. Partin, Assistant Industrial Waste Engineer, Los Angeles County.

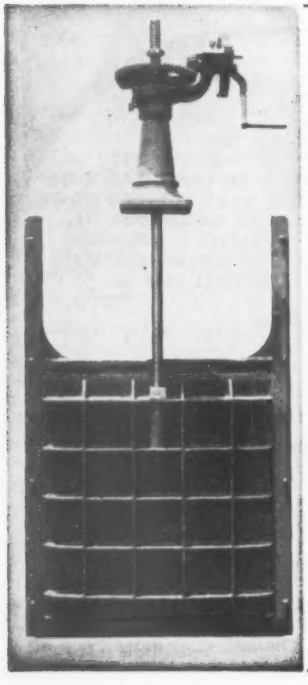
"Re-Use of Water, Ventura County," by a panel consisting of Linne C. Larson, Executive Officer, Regional Water Pollution Control Board No. 4; Horace W. Hindry, Head Mechanical Engineer, Shell Oil Co., Ventura; Walter Witz, Superintendent of Sewage Disposal, Ventura; E. A. Reinke, Chief, Bureau of Sanitary Engineering, State Dept. of Public Health, Sacramento; and R. R. Kennedy, Consulting Engineer, San Francisco.

"Workable Industrial Waste Standards," by N. W. Anderson, Los Angeles County Sanitation Districts.

"Collection, Treatment, and Disposal of the Sewage of San Diego County," by D. H. Caldwell and J. J. Kersnar, Brown and Caldwell, Consulting Engineers, San Francisco.

"Organization and Management Control of a Sewage Treatment Plant," by R. D. Bargman, Assistant Engineer-

(*Continued on page 306a*)



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Superintendent, Hyperion Sewage Treatment Plant, Los Angeles.

"Operating Experiences at the East Bay Municipal Utilities District," by Elmer E. Ross, Plant Superintendent.

"Protective Coatings," by J. R. Galloway, Materials Testing Engineer, Pasadena.

"Safety—Whose Responsibility?" by D. E. Hall, Division of Industrial Relations, State of California.

"Costs and Operating Records," by James L. Carey, Assistant Sewer Maintenance Superintendent, City of Los Angeles.

"Jointing Materials," by A. Collins, Design Engineer, Los Angeles County Engineer Office.

"Laboratory Apparatus and Chemicals—Quick Reference," by Stanley G. Pateman, Chief Operator, Oxnard.

"Some Relations between the Dilution and the Warburg Methods for B.O.D. Determination," by E. W. Lee and W. J. Oswald, Research Engineers, Sanitary Engineering Laboratories, University of California, Berkeley, Calif.

"Application of Molecular Filter Technique to the Bacterial Assay of Sewage," by A. Goetz, Associate Professor of Physics, California Institute of Technology.

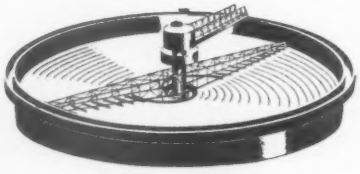
"Operation of a Vacuator with and without Preaeration," by T. J. Mays, Superintendent, Santa Maria.

"Studies on Effects of Ground Garbage in Sewers," by F. R. Bowerman, Sanitary Engineer, Los Angeles County Sanitation Districts.

"Design of a Small Treatment Plant Utilizing Oxidation Ponds," by Russell Ludwig, Consulting Chemist, Pasadena, and Richard Pomeroy, Consulting Engineer, Pasadena.

At the Annual Business Meeting, Arthur T. Wintersgil was nominated to receive the Federation's Arthur Sidney Bedell Award. Other actions in-

(*Continued on page 308a*)



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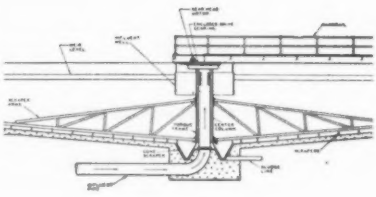

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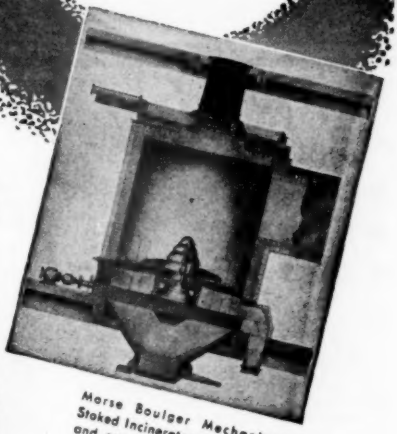

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Representatives in Principal Cities

cluded incorporation of the Association and adoption of new by-laws with an increase of annual dues to $7.00.

Officers elected for 1953–4 were:

President: L. H. Cook, Menlo Park.
1st Vice-President: A. A. Appel, Los Angeles.
2nd Vice-President: H. B. Foster, Jr., Berkeley.
FSIWA Director: F. G. Nelson, Los Angeles.
Secretary-Treasurer: S. A. Weed, Oakland.

The meeting closed with an inspection trip to the Santa Barbara sewage treatment plant.

SAM A. WEED,
Secretary-Treasurer

ARKANSAS WATER AND SEWAGE CONFERENCE

The 1953 Annual Meeting of the Arkansas Water and Sewage Conference was held at the Robinson Memorial Auditorium, Little Rock, Ark., March 16–18, 1953. A total of 182 persons registered for the meeting, tying the previous record, set at the 1951 meeting.

Papers presented at the meeting included:

"Sewage Rates," by Marion L. Crist, Consulting Engineer, Little Rock.

"Operating Records, Systems and Disposal," by L. M. McGoodwin, Consulting Engineer, Fayetteville.

"Experience with Enzymatic Treatment of Sewage," by N. B. Crawford, Superintendent of Light, Water and Sewers, Benton.

"Responsibilities of the Manager," by Allen B. Curry, Consulting Engineer, Little Rock.

"Public Relations," by W. J. Gordon, Manager, Chamber of Commerce, Fayetteville.

"Sinking Funds and How to Set

(*Continued on page 310a*)

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Them Up," by Loren R. Heiple, Professor of Civil Engineering, University of Arkansas, Fayetteville.

The Federation's Bedell Award was presented to Harrison Hale. Officers elected for 1953–4 were:

Chairman: J. H. Wilson, Little Rock.
Vice-Chairman: A. O. Chastain, Wynne.
Secretary-Treasurer: Harrison Hale, Magnolia.

HARRISON HALE,
Secretary-Treasurer

ARIZONA SEWAGE AND WATER WORKS ASSOCIATION

The 1953 Annual Meeting of the Arizona Sewage and Water Works Association was held at the San Marcos Hotel, Chandler, Ariz., April 16–18, 1953. A total of 217 registered for the meeting, including 50 ladies.

Papers presented included the following:

"Algae Symbiosis," by Harvey F. Ludwig, USPHS, Washington, D. C.

"Choosing the Appropriate Differential Producer in Main Line Metering," by E. J. Waltenspiel, Builders-Pacific, Inc., Phoenix.

"Ground Sewer Pipe Joints," by John R. Boughton, Chief Engineer, Gladding McBean & Co., Los Angeles, Calif.

"Simple Tests for Sewage and Water Treatment Plants," by A. L. Mathis, Chemist, Division of Water and Sewers, Phoenix.

The following officers were elected:

President: W. C. Harford, Phoenix.
1st Vice-President: P. J. Martin, Jr., Tucson.
2nd Vice-President: G. T. Rekerdre, Tucson.
Secretary-Treasurer: M. V. Ellis, Phoenix.

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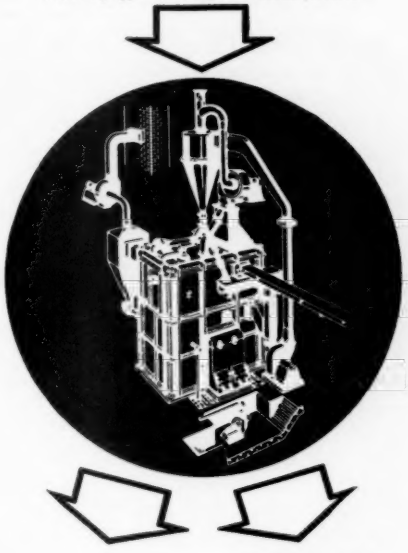
SLUDGE
As a vacuum filter cake or thickened sludge from any type of sewage treatment process.



ASH and/or **FERTILIZER**

As a fine dust, free from clinker and unburned organic materials.

As a dry powder, containing all the original fertilizer ingredients.

Effective as modern processes of sewage *treatment* are, they can lose much of their value if proper sludge disposal methods are not adopted.

The C-E Raymond System of Flash Drying and Incineration offers two completely modern methods of sewage sludge disposal — both performed by compact, reliable equipment.

Flash Drying by the C-E Raymond System is a continuous process in which vacuum filtered sludge — if uncontaminated with undesirable industrial wastes — is efficiently heat dried to a marketable fertilizer or soil conditioner retaining all its original nitrogen, but eliminating the objectionable qualities of the original wet sludge. In a well designed and operated "activated plant" the revenue from the sale of fertilizer is sufficent to cover the operating costs of both the drying and vacuum filtration.

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Bactericide and Sanitizer—A new technical bulletin describes an unusual material known as Chorpactin KCW, which produces high concentrations of available hypochlorous acid. The powdery material is recommended as a bactericide, sanitizer, and odor-removal agent.—Guardian Chemical Corp., 10–15 43rd Ave., Long Island City, N. Y.

pH and Conductivity Controllers—New 24-page Catalog 1550 describes and gives details on measurement and control of pH, redox, and conductivity, as well as application information.—Minneapolis-Honeywell Regulator Co., Wayne and Windrim Aves., Philadelphia 44, Pa.

Saran-Lined Nozzle—Bulletin 130–J6 gives pertinent information on the uses of a new Saran-lined Venturi nozzle for metering corrosive liquids and slurries.—Builders-Providence, Inc., 345 Harris Ave., Providence 1, R. I.

Flow Test Kit—Supplement 1 to Catalog 33 describes a new portable, wide-range flow test kit for laboratory and field flow work.—Fischer & Porter Co., 745 Jacksonville Road, Hatboro, Pa.

Mechanical Seal—Information and engineering data are available on a new all-purpose mechanical seal for rotary shaft applications.—Dept. S–12, Crane Packing Co., 1800 Cuyler Ave., Chicago 13, Ill.

Herringbone Gear Drives—New 36-page book (No. 2519) gives detailed information on herringbone gear drives, together with installation data and specifications.—Link-Belt Co., 307 N. Michigan Ave., Chicago 1, Ill.

Ratio Controllers—New Application Engineering Data Sheet 833–9 gives a complete description of automatic control details for activated sludge plants.—The Foxboro Company, 26 Neponset Ave., Foxboro, Mass.

Flow Meter—Bulletin No. 401 details all salient characteristics of mercury flow-type indicating, recording, and totalizing unit operating on any enclosed basic element.—Simplex Valve & Meter Co., 68th and Upland Sts., Philadelphia 42, Pa.

Helical Gear Drives—Book No. 2451 gives 16 pages of design and application data for double and triple reduction types of helical gear drives.—Link-Belt Co., 307 N. Michigan Ave., Chicago 1, Ill.

Pipe Compound Melting Pots—New, improved, portable, sewer pipe compound melting pots in 15-, 25-, and 50-gal. capacities are available for either bottled gas or kerosene fueling.—Aeroil Products Co., Inc., Wesley St., South Hackensack, N. J.

Electrical Equipment Service—New bulletins list the stocking points for standard general-purpose electrical control devices.—General Electric Co., 1 River Road, Schenectady, N. Y.

Combined Motor-Pump—Application data and specifications for a new magnetically-driven combined motor and centrifugal pump requiring no seals or stuffing boxes are given in Bulletin G1000. Capacities up to 150 g.p.m. at pressures up to 150 p.s.i. are described.—Chempump Corp., 1300 E. Mermaid Lane, Philadelphia 18, Pa.

Diesel Engines—Opposed-piston diesels in the 225- to 750-hp. range are available in new, small, light-weight, self-contained units that also can be equipped for dual-fuel and spark-ignition gas operation.—Fairbanks, Morse & Co., 600 S. Michigan Ave., Chicago 5, Ill.

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It's another example of how sturdy concrete pipe meets any combination of site conditions or drainage requirements.

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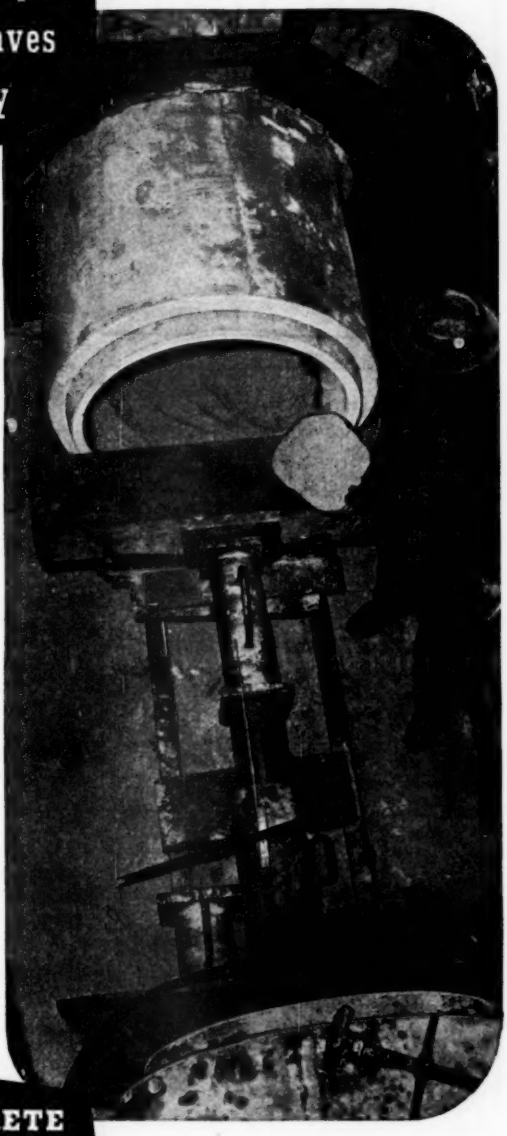

Jacking 36-inch concrete pipe under 14 lines of railroad track at Gary, Ind. The end of 50 feet of pipe jacked into position is shown in lower part of photo. This section is being used as backstop for jacking pipe in opposite direction.

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